This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

Mansfie

ELECTROMAGNETS;

THEIR DESIGN, AND CONSTRUCTION.

BY

A. N. MANSFIELD, S. B.

NEW YORK PUBLIC LIBRARY

SCIENCE DEPT.

NEW YORK
D. VAN NOSTRAND COMPANY.
23 Murray and 27 Warren Streets.
1901.

THE NEW YORK
PUBLIC LIBRARY
498568
ASTOR, LENOX AND
TILDEN FOUNDATIONS.
R 1912 L

Copyright, 1901, by D. VAN NOSTRAND CO.

PREFACE.

THIS volume is the outgrowth of an attempt to revise Number 64 of "Van Nostrand's Science Series," *i. e.*, "Electromagnets, the Determination of the Elements of their Construction," by T. H. Du Moncel. It was found impossible to revise it without completely rewriting it, and it was deemed best to publish what follows as a new number in the "Science Series."

No claim is made for originality, but it has been attempted to collect, in a convenient form, formulæ and data which are essential to the design and construction of electromagnets for various purposes. We are indebted especially to the following: S. P. Thompson, "The Electromagnet;" Du Bois, "The Magnetic Circuit in Theory and Practice;" Jackson, "A Text Book on Electromagnetism." Other sources of information have been indicated in the foot-notes.

CONTENTS.

CHAPTER I.

PAGE
Historical 9
Magnetic properties 13
Classification of electromagnets 16
Forms of electromagnets 17

CHAPTER II.

Properties of the magnetic circuit 22
Effect of air gap 34
Effect of joints 35
Magnetic leakage 36
Hysteresis 42
Retentiveness 45
Table of permeabilities 49
Limits of magnetization 50
Magnetic testing 50

CHAPTER III.

Materials of construction 59
Form of cross section of core 62
Table giving thickness and weight of insulation on wires 65
Formulæ for winding 67
Density of current in winding 80
Heating of magnet coils 81
Permissible amperage and depth of winding 85
Weight of magnet winding 90

PAGE
Relations between constants of coils....... 91
Relation of resistance of winding to resistance of external circuit................. 95

CHAPTER IV.

Tractive electromagnets.................. 99
Table giving relation between magnetization and traction............................ 103
Attractive electromagnets.................106
Design of tractive electromagnets......... 117
Electromagnets for producing strong fields 122
Polarized mechanisms.................... 123
Electromagnets for use with currents of brief duration......................... 127

CHAPTER V.

Alternate current electromagnets......... 135
Hysteresis loss........................... 137
Eddy current loss......................... 138
Attraction and repulsion of alternating current conductors........................ 141

APPENDIX.

Tables giving relation between U. S. and metric systems......................... 151
Properties of copper wire B & S gauge..... 152
Properties of copper wire B W gauge..... 153
Temperature coefficients.................. 154
Weight of copper in 100 pounds of insulated wire.............................. 155

ELECTROMAGNETS.

CHAPTER I.

SIMPLE ELECTROMAGNETS.

1.—HISTORICAL.

In 1820 Oersted discovered that the neighborhood of a conductor conveying an electric current possessed magnetic properties. When a magnetic needle is brought near the conductor it is deflected, this effect being due to the presence of magnetic lines of force about the conductor.

In September of the same year, Arago described how he had communicated permanent magnetism to steel needles by laying them at right angles to a conductor conveying a current of electricity. Acting upon a suggestiòn of Ampere's, he greatly increased the magnetic effect by substituting a helix of wire for the straight conductor, and placing the steel needle in the axis of the helix.

William Sturgeon was the first to devise an apparatus in which a soft iron core surrounded by a coil of copper wire, could be made to act as a magnet. Such an apparatus is known as an *electromagnet.* Sturgeon described his first apparatus in a paper to the Society of Arts in 1825. He exhibited, with others, two electromagnets, one of the horse-shoe type, and one a straight bar.

Interest was aroused and much experimental work was done by various investigators. In the United States, Prof. Henry, of Albany and Princeton, was an ardent investigator from the year 1828. Prof. Henry "was the first to actually magnetize a piece of iron at a distance, and to call attention to the fact of the applicability of his experiments to the telegraph."* He also "was the first to prove by actual experiment that in order to develop magnetic power at a distance, a galvanic battery of 'intensity' must be employed to project the current through the conductor, and that a magnet surrounded by many turns of one long wire must be used to receive this current."*

---

* Scientific Writings of Joseph Henry, Vol. II., p. 435.

About 1838, Joule of Manchester, began that work which added much to the knowledge of the laws of the electromagnet. Joule obtained an insight into the laws of the magnetic circuit and "found it disadvantageous to increase the length (of the iron core) beyond what is needful for the winding of the covered wire."† He did much work on the lifting power of magnets and propounded the law that the "attractive force of two electromagnets for one another is directly proportional to the square of the electric force to which the iron is exposed ; or if E denote the electric current, W the length of wire, and M the magnetic attraction, $M=E^2 W^2$."‡ The researches of Joule may be said to end the first stage in the development of the electromagnet.

---

* Scientific Writings of Joseph Henry, Vol. II., p. 435.

† Joules' Scientific Papers, Vol. I., p. 8.

‡ Ibid, p. 13.

Joule's notion of the magnetic circuit was not well received by physicists and experimenters. Work was carried on by many experimenters, among the more prominent being Müller, Dub, Du Moncel, Lenz, and Jacobi. They formulated the results of their investigations into empirical rules and laws, and little was based on theory.

It is since 1880 that the magnetic circuit has been investigated mathematically and the results of this work, combined with experiment, have placed the laws of magnetic circuits upon a sound and practical footing. The work of Maxwell, Rowland, Bosanquet, Hopkinson, Kapp, Ewing, DuBois and others has all contributed towards this end. The consideration of the electromagnet is the consideration of the laws of the magnetic circuit, and this necessitates a knowledge of the magnetic field and the magnetic properties of iron. The study of the magnetic field and the magnetic properties of iron has been largely contributed to by Ewing, Steinmetz, Ebert and others.

2. MAGNETIC PROPERTIES.

The region surrounding a conductor conveying an electric current possesses magnetic properties, as is manifest by its action upon magnetic substances, placed within it. A *magnetic force* exists in the region, and that region is called a *magnetic field.* The direction of the magnetic force in a magnetic field is indicated by *lines of force.*

Lines of force, having the form of concentric circles with the conductor as a center, surround a current conveying conductor and lie in a plane perpendicular to the conductor. Direction is as-

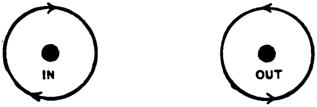


Fig. 1.

cribed to these lines of force, and it is dependent upon the direction of the current. The directions are connected by the following relation: if one looks along a conductor in the direction in which the current is flowing, the positive direction of the lines of force is in the direction of motion of the hands of a watch. These directions are associated in Fig. 1.

The magnetic action of a current is increased, or concentrated, if instead of a linear conductor, the wire is given the form of a helix. The lines of force surround the conductor and pass through the center of the helix as shown in Fig 2.

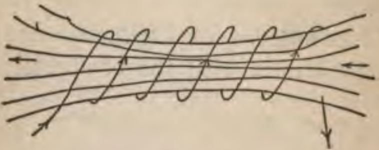


Fig. 2.

Such an arrangement is called a *solenoid.* A solenoid has the properties of a permanent magnet, i.e., has a magnetic field; attracts and repels magnetic bodies, etc.

The magnetic action of the solenoid is greatly increased if a core of soft iron is inserted into the helix; during the passage of a current through the coil, the core becomes strongly magnetic. The combination of coil and core forms an electromagnet.

The lines of force, or *magnetic flux*, generated by the current pass through the iron core, out at one end, through the air or surrounding medium and reenter the iron core at the other end. The end at which the lines of force are assumed to leave the core is called the north pole, and the end at which they are assumed to enter the core is called the south pole.

There are numerous rules for telling the polarity of an electromagnet when the direction of the current is known, one of the simplest being that of Jamieson, *i. e.*: place the right hand upon the winding so that the current is flowing in the direction of from wrist to finger-tips; the extended thumb points in the direction of the north pole.

3. CLASSIFICATION OF ELECTROMAGNETS.

There are three main divisions according to the functions of the electromagnet.

(a) *Attractive* electromagnets, namely, those in which the armature is attracted, generally from a distance, when a current flows through the coil.

(b) *Portative* electromagnets, namely, those which are used for temporary adhesion or lifting power.

(c) *Field* electromagnets, namely, those which are used for producing a magnetic field of fixed strength, as in a dynamo or motor.

Attractive electromagnets can be further subdivided into:

(a) *Polarized*, namely, those in which the armature is a permanent magnet and is either attracted or repelled by the core, depending upon the direction of the current in the coil.

(b) *Non-polarized*, namely, those in which the armature is of soft iron and the resultant action between the core and armature is always one of attraction.

4. FORMS OF ELECTROMAGNETS.

While there are many forms of electromagnets they may be, for most purposes, classified as follows:

1. Bar electromagnets.
2. Horse-shoe electromagnets.
3. Iron-clad electromagnets.
4. Coil and plunger electromagnets.
5. Special forms of electromagnets.

Bar electromagnet. This is the simplest form of electromagnet and consists of a straight iron bar surrounded by a coil of insulated wire as shown in Fig 3.

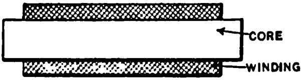


Fig. 3.

One of the principal uses of this form is in the telephone receiver.

Horse-shoe electromagnet. This type of electromagnet is very extensively used, the iron core being of a U or horse-shoe shape, as shown in Fig. 4.

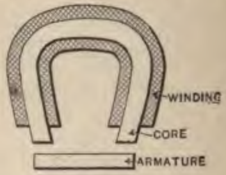


Fig. 4.

The core may be bent from a rod of iron, or two separate iron-cores may be connected by a third piece of iron, or the *yoke.* The winding may be uniformly distributed over the core in the bent

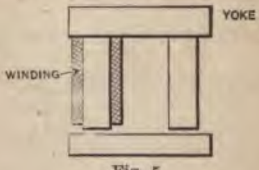


Fig. 5.

form, may be collected on the two legs or cores, may be collected on one core, or may be collected on the yoke. When the winding is collected on one core or leg, as shown in Fig. 5, it is known as a *club-foot* electromagnet.

Iron-clad electromagnet. This form may be considered as a simple bar magnet having an iron shell outside of the coil and attached to the core at one end; or it may be considered as a form of the club-foot magnet with one leg divided and surrounding the coil, as shown in Fig. 6.

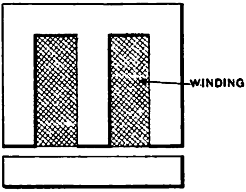


Fig. 6.

The iron shell forms a mechanical and magnetic shield to the winding. The free end of the core presents one pole and

CHAPTER II.

1. PROPERTIES OF THE MAGNETIC CIRCUIT.

Unless otherwise specified, a close
ring of soft iron uniformly wound wil
be considered in what follows.

When a current flows through the wind
ing of an electromagnet, a magnetic forc
is generated which sets up and maintains
magnetic state or stress in the core. Th
core is said to be traversed by a *magneti*
flux or by *magnetic induction.* The *in*
tensity of the magnetic induction, or th
flux density is measured by the numbe
of lines of force which pass through
unit (square centimeter) area in a direc
tion at right angles to the lines of force
and it is generally denoted by the letter B

The force which produces this magnet
ic induction is called the *magnetomotiv*
force and the magnetomotive force pe
unit length (cm.) of magnetic circuit i
called the *magnetizing force ;* the forme

being generally abbreviated to M.M.F., or simply M, and the latter being generally denoted by the letter H.

If N represents the total number of spirals, or convolutions, in the winding surrounding the ring, and I the amperes flowing, the product NI is called the *number of ampere-turns*. The relation which exists between ampere-turns and M is

$$M = \frac{4\pi}{10} NI = 1.257 \ NI. \qquad (1)$$

If l is the length (mean perimeter) of the ring in cms.

$$H = \frac{M}{l} = 1.257 \frac{NI}{l}. \qquad (2)$$

If $n = \frac{N}{l}$, i.e., n is the number of convolutions per centimeter length,

$$H = 1.257 \ nI \qquad (3)$$

= 1.257 times the ampere-turns per centimeter.

If l is given in inches

H = 0.495 times the ampere-turns per inch.

The density of the magnetic flux, which is produced by a given M.M.F., depends upon the configuration and material of the core. The flux density produced in a magnetic body is many times greater than that produced in a non-magnetic body of the same dimensions. That property of the core which limits the flux density is called the *magnetic reluctivity* of the material. Air is taken as the standard of comparison, and the reluctivity of a cubic centimeter of air is taken as unity. The reluctivity of all non-magnetic substances is practically unity, and the reluctivity of magnetic substances is very small as compared to that of air. The reluctivity of a body multiplied by its length and divided by its cross-sectional area is called its *reluctance.*

The following relations exist between the several magnetic quantities referred to above, where l is the mean perimeter of the ring (cms.) and s its cross-sectional area (sq. cms).

First $$F = Bs \qquad (4)$$

that is, the total flux or induction equals the flux density multiplied by the cross-sectional area.

Second. $$M = Hl. \qquad (5)$$

that is, the magneto-motive force equals the product of the magnetizing force and the length of the magnetic circuit.

Third. $$B = \mu H \qquad (6)$$

that is, the magnetic induction equals the magnetizing force multiplied by a factor μ, which is called the *permeability* of the material. The permeability is

$$\mu = \frac{B}{H}. \qquad (7)$$

μ is dependent upon the quality of the iron and the extent of the magnetization.

A curve which shows graphically the relation between the induction B and the magnetizing force H is called a *curve of magnetization*, and has the general shape shown in Fig. 8.

The curve which shows the relation

between the permeability μ and the induction B is called the *permeability curve*,

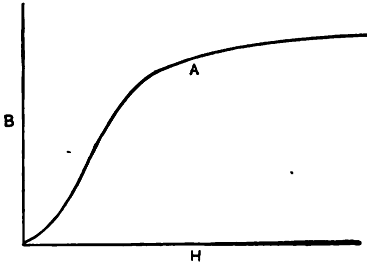


Fig. 8.

and has the general shape shown in

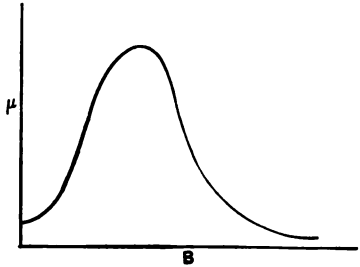


Fig. 9.

Fig. 9. This curve may be constructed from the curve of magnetization.

For small magnetizing forces the permeability is small; as H increases μ increases and therefore B; after reaching a certain point the permeability begins to decrease, and this corresponds to a bend in the magnetization curve as at A, Fig. 8. At this stage the iron is said to be approaching saturation. A knowledge of the relation between B, H, and μ for different qualities of iron is essential in the design of all electromagnetic apparatus.

Fourth.

$$S = \frac{1}{\mu} = \frac{H}{B} \cdot \qquad (8)$$

that is, the *magnetic reluctivity* is equal to the reciprocal of the permeability, or to the magnetizing force divided by the induction.

Fifth.

$$P = \frac{\mu s}{l} \cdot \qquad (9)$$

that is, the *permeance*, P, equals the permeability multiplied by the cross-sectional area of the magnetic circuit, and the product divided by the length of the circuit.

Sixth. The reciprocal of the permeance

$$X = \frac{1}{P} = \frac{l}{\mu s} = \frac{Sl}{s}\cdot \qquad (10)$$

that is, the *reluctance*, X, equals the reluctivity multiplied by the length of the circuit and divided by the cross-sectional area of the circuit. The reluctivity is the reluctance per unit volume.

From a consideration of the above equations the following relations hold:

$$B = \mu H. \qquad (6)$$

Multiplying both sides of the equation by $\frac{s}{l}$ and transforming

$$Bs = \frac{\mu s}{l} Hl.$$

or

$$F = MP = \frac{M}{X}\cdot \qquad (11)$$

i. e. the total flux is equal to the magnetomotive force multiplied by the permeance, or divided by the reluctance. This proposition for the magnetic circuit is analogous to Ohm's Law for the electric circuit; this difference must however be noted, that the electrical resistance is absolutely independent of the strength of of the current, depending upon the material of the conductor, its temperature and its geometrical dimensions; while the magnetic resistance or reluctance of the magnetic circuit is dependent upon the magnetic intensity, being low for low intensities, increasing to a maximum and then decreasing and approaching unity when the magnetizing force is high. The analogy of Ohm's Law to magnetic circuits is only an artifice to facilitate investigation.

The above relation of the magnetic circuit may be written

$$\text{Magnetic Flux} = \frac{\text{Magnetomotive Force}}{\text{Reluctance}}. \tag{12}$$

Names have been given to the magnetic terms analogous to the electric terms. One ampere turn is frequently used the unit of M.M.F. Another unit called the *gilbert*, is in use, one gilbert being equal to $\frac{10}{4\pi}$ (= 0.796) ampere turns, or one ampere turn is equal to 1.257 gilberts. The unit of reluctance is called the *oersted*, and is equal to the reluctance which is offered to the passage of magnetic flux, by a cubic centimeter of air when measured between parallel faces. The unit of magnetic flux is called the *weber*, and is the amount of flux which would pass through a magnetic circuit whose reluctance is one oersted, when the M.M.F. acting is one gilbert. The law of the magnetic circuit can then be written

$$\text{Webers} = \frac{\text{Gilberts}}{\text{Oersteds}} \qquad (13)$$

The magnetic density, i. e. the flux per unit area is called the *gauss*, and is a density of one weber passing perpendicularly through an area of one square centimeter.

Substituting the value of H as given in (2) we have

$$B = \mu H = \frac{4\pi}{10}\mu\frac{NI}{l} = 1.257\frac{\mu NI}{l}.$$

Also

$$F = \frac{M}{X} = \frac{Hl}{\frac{l}{\mu s}} = \frac{\frac{4\pi}{10}NI}{\frac{l}{\mu s}}, \qquad (14)$$

or

$$F = \frac{1.257\ NI}{\frac{l}{\mu s}}. \qquad (15)$$

which may be called the fundamental law of the simple magnetic circuit.

Transposing, $NI = 0.795\ F \times \frac{l}{\mu s}$. (16)

If inch measure is used,

$$NI = 0.3132F \times \frac{l^1}{\mu s^1}, \qquad (17)$$

the prime mark being added to denote inch measure.

When the magnetic circuit consists of several parts, such as cores, yoke, armature and air gaps; or of parts with different cross-sectional areas and permeabilities, whose separate reluctances are x_1, x_2, x_3, etc., the total reluctance of the circuit is

$$X = x_1 + x_2 + x_3 + \dots\dots \quad (18)$$

The reluctance of a circuit is equal to the sum of the reluctances of the component parts, as in a series electrical circuit the total resistance is the sum of the separate resistances.

Let μ_1, μ_2, μ_3, etc., l_1, l_2, l_3, etc., s_1, s_2, s_3 etc. represent respectively the permeabilities, lengths, and cross-sectional areas, of the several component parts of a magnetic circuit, then

$$X = \frac{l_1}{\mu_1 s_1} + \frac{l_2}{\mu_2 s_2} + \frac{l_3}{\mu_3 s_3} +, \text{etc.} \quad (19)$$

$$\text{and } F = \frac{1.257NI}{\frac{l_1}{\mu_1 s_1} + \frac{l_2}{\mu_2 s_2} + \frac{l_3}{\mu_3 s_3} + \dots} \quad (20)$$

Transposing have

$$\mathrm{NI} = \frac{\mathrm{F} \times \left\{ \frac{l_1}{\mu_1 s_1} + \frac{l_2}{\mu_2 s_2} + \frac{l_3}{\mu_3 s_3} + \ldots \right\}}{1.257} \quad (21)$$

that is

$$\mathrm{NI} = 0.795\mathrm{F} \left\{ \frac{l_1}{\mu_1 s_1} + \frac{l_2}{\mu_2 s_2} + \frac{l_3}{\mu_3 s_3} + \ldots \right\} \quad (22)$$

when the dimensions of the circuit are expressed in centimeters.

If the unit of measurement is the inch, the formula becomes

$$\mathrm{NI} = 0.3132\mathrm{F} \left\{ \frac{l_1^1}{\mu_1 s_1^1} + \frac{l_2^1}{\mu_2 s_2^1} + \frac{l_3^1}{\mu_3 s_3^1} + \ldots \right\} \quad (23)$$

What amounts to the same as is expressed by formulae (22) or (23), is to apply (16) or (17) to each separate portion of the magnetic circuit and determine the ampere-turns required to maintain the flux F through that portion of the circuit. The sum of the ampere-turns thus determined gives the total ampere-faces be accurately finished, so as to make the joint as close as possible. As noticed above, if the circuit is worked near the saturation point, the influence of the joint is not so pronounced. Where joints occur between portions of the same circuit, and these portions are of different permeabilities, the cross-sectional area of the joint, or the total area perpendicular to the flux should be equal to the cross-sectional area of that portion of the circuit having the lowest permeability.

Magnetic Leakage.—In an electromagnet the magnetic circuit can be considered as made up of three parts: the cores and yoke, the armature, and the air space, or joint, between armature and cores. When the armature is in contact with the cores, the reluctance of the circuit is low and practically made up of the iron reluctance. When there is an air gap the reluctance is greatly increased, and is made up mostly of the gap reluctance. In this case there is a considerable leakage of lines of force across from core to core, as indicated in Fig. 10.

The leakage paths are in parallel with the useful path for lines of force through the cores and armature. The number of lines of force in each path varies inversely as the reluctance and directly as the magnetomotive force which is acting. The laws of parallel circuits can be applied to magnetic circuits, as they are applied to electric circuits, but the dimensions and conditions of the former are not as definite as in the case of the latter.

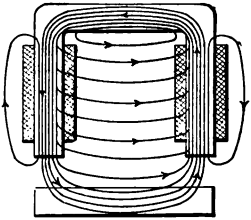


Fig. 10.

The reluctance between surfaces of

different shapes, sizes and inclinations can be deduced, but the one of principal import in electromagnet design is that between parallel cylindrical surfaces. If the diameter of the cylinders is d, the distances between their centers is b, and their length is l, the air reluctance* between the cylinders is

$$X = \frac{0.737 \log._{10} \frac{a_1}{a_2}}{l} \qquad (27)$$

where $$\frac{a_1}{a_2} = \frac{d}{b - \sqrt{b^2 - d^2}} \qquad (28)$$

The numerical value of $\frac{a_1}{a_2}$ is constant for all dimensions as long as the ratio $\frac{b}{d}$ is constant.

The following table† gives the magnetic reluctance in c.g.s units between unit lengths of two equal parallel cylinders surrounded by air and having various values of the ratio $\frac{b}{d}$.

---

* Jackson, "Electro-Magnetism and the Construction of Dynamos," p. 131.

† Taken, by permission of the publishers, from Professor Dugald C. Jackson's Text-Book on Electromagnetism and the Construction of Dynamos, copyright by The Macmillan Company, 1893.

$\frac{b}{d}$	X per cm.	$\frac{b}{d}$	X per cm.	$\frac{b}{d}$	X per cm.
1.25	0.19	4.0	0.655	7.5	0.86
1.50	0.30	4.5	0.67	8.0	0.88
1.75	0.337	5.0	0.73	8.5	0.90
2.00	0.42	5.5	0.76	9.0	0.92
2.50	0.50	6.0	0.79	9.5	0.94
3.00	0.556	6.5	0.815	10.0	0.96
3.50	0.61	7.0	0.84		

If the dimensions of the cylinders are given in inches, X per cm. must be divided by 2.54 to give X per inch. Hence, to find the reluctance between any two cylinders, find the value of $\frac{b}{d}$ from the dimensions, and take the proper value of X per cm. or inch, and divide by the length of the cylinder in cms. or inches.

Consider an electromagnet in which the magnetizing coil is wound upon the keeper, or yoke, as in Fig. 11.

In this case the magnetomotive for[illegible] may be considered as acting between [illegible] leakage surfaces, and also across the [illegible] gap between pole pieces and armature.

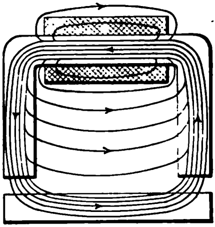


Fig. 11.

The following approximate relations hold. The total leakage lines are

$$N_l = \frac{M}{X_l} = MP_l,$$

where X_2 and P_2 are the reluctance and permeance of all the leakage lines in parallel. The useful lines are

$$N_a = \frac{M}{X_a} = MP_a,$$

where X_a and P_a refer to the circuit made up of cores, air gap, yoke and armature. The total number of lines of force generated is

$$N_t = N_l + N_a,$$

and the ratio

$$\frac{N_t}{N_a} = \frac{X_a + X_l}{X_l} = \frac{P_a + P_l}{P_a}.$$

The ratio $\frac{N_t}{N_a}$ is denoted by the letter v, and is called the leakage coefficient. When the reluctance X_a is small, the leakage coefficient is about unity.

When the magnetizing coils are divided between the two legs of an electromagnet, as shown in Fig. 10, the leakage lines cannot be considered as directly proportional to P_l. The difference of magnetic pressure between A and B is approximately zero, and that between C and D approximately equal to M, and hence the average difference of magnetic pressure between the two legs is $\frac{M}{2}$.

Hence, $$N_1 = \frac{M}{2X_1} = \frac{M}{2} P_1.$$

From this consideration the value of v may be found.

If the reluctance of the cores is not small, the magnetic pressure acting between C and D cannot be considered as M, and the problem is complicated by corrections to be applied for this effect.

From the above consideration it is seen that in general the more uniformly the winding is distributed over the magnetic circuit the less the leakage.

Roundness and evenness of the magnetic circuit, avoidance of sharp corners and abrupt turns, all tend to reduce leakage to a minimum.

Hysteresis.—When a piece of iron is subjected to a series of gradually increasing magnetizing forces, beginning at zero, the resultant induction increases until the iron becomes saturated. The relation between B and H can be plotted as a curve, which has the general form shown in Fig. 8. If now the magnetizing force is gradually decreased from this maximum value to zero, it will be found that the resultant flux does not have the same value for corresponding values of H, in the increasing and decreasing series of values of H; being greater in the decreasing series. The magnetic flux in a piece of iron, or other magnetic material, depends upon the previous values of the M.M.F. as well as the present ones. The flux lags behind the magnetizing force, and this lagging is known as *hysteresis.*

When the iron is subjected to a complete cycle of changes of magnetizing forces, that is, from zero to a positive maximum, then back to zero, then to a negative maximum, and back to zero, and the relation between B and H is plotted, the flux lags behind the M.M.F., and produces a closed loop, as shown in Fig. 12.

This loop is known as the *hysteresis loop.* The area enclosed by the hysteresis loop is a measure of the energy lost in each unit volume per cycle of change; this loss of energy is made manifest in the form of heat in the iron. The hysteresis action then produces a loss of energy by heating, and in the case of alternate current apparatus may produce serious heating.

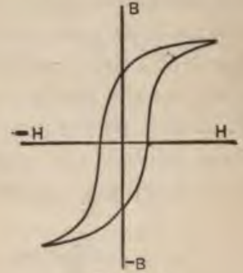


Fig. 12.

The energy loss due to heating is given for a wide range of flux densities by the following formula, due to Steinmetz.

$$w = f_n \, B_{max}^{1.6}, \qquad (29)$$

where

w = watts lost per cubic centimeter of iron.

f = number of cycles per second.
B = maximum induction per sq. cm.
and
η = a constant varying from 0.002 for soft iron to 0.004 or 0.0045 for transformer irons.

Annealing, while it promotes homogeneity in the iron and increases the permeability of the hysteresis, also increases the constant if it be originally very small.

Retentiveness.—When a piece of iron has been magnetized and the magnetizing force withdrawn, the magnetization does not entirely disappear, but a greater or less amount remains, depending upon the quality of the iron. That portion of the magnetization which remains is called *residual magnetization*, and that property of retaining magnetization is known as the *magnetic retentivity* or *retentiveness* of the iron. The iron acts as if an internal M.M.F. was present and tended to maintain the magnetic flux. This force is called the *coercive force.*

Soft irons have a small retentiveness, while that of hard steel is high.

Retentiveness produces a sticking of the armature in electromagnetic mechanisms, but when the armature is detached from the pole pieces the retentiveness practically disappears.

From the above, it is seen that the magnetic properties of iron play an important part in the design and efficiency of electromagnets, as the reluctance of the circuit depends upon the quality of the iron used.

In general, it may be said that the magnetic properties of iron and steel depend upon the percentage of carbon present, and to a less degree upon the percentage of sulphur, phosphorus, manganese, silicon, and other impurities.

The qualities of several different grades of iron are as follows:

Cast Iron.—Cast iron is hard and comparatively brittle. It contains considerable carbon, part of it in a combined state and the rest in a free state. Irons containing more than 0.8 per cent of combined carbon are of a low magnetic permeability, and those having less than 0.3 per cent are of a high permeability. The combined carbon should be kept as low as possible, while the free carbon may vary from 2 to 3 per cent without having any marked effect on the permeability. Cast iron has a low cost, and can easily be obtained in any desired shape.

Wrought Iron.—Wrought iron is comparatively soft, malleable, and ductile. It contains a very small percentage of carbon. Wrought iron shows uniformly high permeability. It is hard to produce cheap in any but the simplest shapes.

Cast Steel.—This has a very small percentage of combined carbon and no free carbon. Good cast steel should not contain more than 0.25 per cent of carbon. It also contains phosphorus, silicon, manganese and sulphur as impurities.

In exact work, the permeability should be obtained for a sample of each lot of

iron used. The following table, t
from Wiener's "Dynamo Electric
chines," p. 311, gives the general
tionship between induction and per
bility for several grades of iron.
results given are the average permea
ties of a large number of tests of th
rious grades.

PERMEABILITIES OF DIFFERENT KINDS OF IRON AT VARIOUS MAGNETIZATIONS.

DENSITY OF MAGNETIZATION.		PERMEABILITY μ.			
Lines per Sq. Inch. B_1	Lines per Sq. cm. B	Annealed Wrought Iron.	Comm'l Wrought Iron.	Gray Cast Iron.	Ordin'y Cast Iron.
20,000	3,100	2,600	1,800	850	650
25,000	3,875	2,900	2,000	800	700
30,000	4,650	3,000	2,100	600	770
35,000	5,425	2,950	2,150	400	800
40,000	6,200	2,900	2,130	250	770
45,000	6,975	2,800	2,100	140	730
50,000	7,750	2,650	2,050	110	700
55,000	8,525	2,500	1,980	90	600
60,000	9,300	2,300	1,850	70	500
65,000	10,100	2,100	1,700	50	450
70,000	10,850	1,800	1,550	35	350
75,000	11,650	1,500	1,400	25	250
80,000	12,400	1,200	1,250	20	200
85,000	13,200	1,000	1,100	15	150
90,000	14,000	800	900	12	100
95,000	14,750	530	680	10	70
100,000	15,500	360	500	9	50
105,000	16,300	260	360		
110,000	17,400	180	260		
115,000	17,800	120	190		
120,000	18,600	80	150		
125,000	19,400	50	120		
130,000	20,150	30	100		
135,000	20,900	20	85		
140,000	21,700	15	75		

Limits of Magnetization.—Iron is said to be saturated when a very material increase in the magnetizing force does not appreciably increase the magnetic flux. This limit of saturation in different qualities of iron is reached at the values given in the following table:*

VALUE OF B.

	Per Sq. cm.	*Per Sq. Inch.*
Wrought Iron........	20,200	130,000
Cast Steel............	19,800	127,500
Mitis Iron............	19,000	122,500
Cast Iron (ordinary)...	12,000	77,500

The practical working densities are about two-thirds of the densities given in the above table.

Magnetic Testing.—The relation between magnetizing force, permeability, and induction may be obtained in numerous ways. The methods may be broadly divided into four general classes:

(1) Magnetometric.
(2) Balance.
(3) Inductive or Ballistic.
(4) Tractive.

---

* Wiener, Dyn. Elec. Machinery, p. 313, Table LX

For a general description of the methods, the reader is referred to Ewing, "Induction in Iron and other Metals;" Du Bois, "The Magnetic Circuit in Theory and Practice;" also a paper by Ewing in the "Proc. Inst. Civ. Eng.," Vol. CXXVI (1896).

Two methods which can be generally used are the ballistic and tractive methods.

Ballistic Method.—This method may be subdivided, in accordance with the form which the test piece of iron takes, into the Ring Method and the Bar and Yoke Method.

The method depends upon the measurement of the transient electric pressure induced in a small test coil, wound around the test piece, when the induction in the test piece is changed. A sample of the iron to be tested is inserted in a magnetic circuit whose magnetizing force is accurately known. A small test coil of known dimensions surrounds the test piece and is connected to a ballistic galvanometer. The induction passing through the coil is caused to vary by making, breaking, or reversing the magnetizing current; or the test coil is suddenly removed to a position where the intensity of the field may be neglected. The value of the induction may be obtained from the throw of the ballistic galvanometer needle, when the constant of the galvanometer is known. This constant may be obtained in several ways, as explained in the above references, or in Jackson's "Electro Magnetism and the Construction of the Dynamo." The ballistic method may be used for measuring fields of any intensity.

Ring Method.—The general arrangement of the apparatus in the ring method is shown in Fig. 13.

A is a ring made of the iron to be tested, and is wound with a magnetizing coil, P, which is in series with a source of current, D, through an adjustable resistance, such as a lamp bank. A double throw switch, Sw, is connected into this

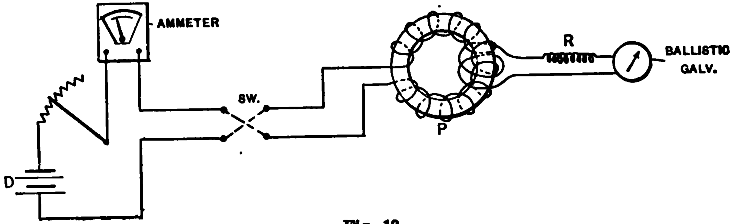


Fig. 18.

primary circuit, so that the direction of current through the coil may be reversed. A secondary winding is connected to a ballistic galvanometer, through an adjustable resistance, R. The magnetizing force is

$$H = \frac{1.25\ NI}{10\,l}.$$

When the primary circuit is made or broken, a deflection is produced in the ballistic galvanometer proportional to the magnetic flux through S ; i.e., $B = kd$, where d is the deflection. The constant, k, of the ballistic galvanometer has to be obtained by calibration.

The advantages of this method are that it only requires a ring of iron, which may be cast from the desired lot or "run"; there is no finishing of the piece to obtain good joints; and the apparatus is much easier to set up and work than the yoke method.

A cylindrical specimen may be used if the ratio of $\frac{\text{length}}{\text{diameter}}$ is great, and the secondary is wound over a short portion of the bar.

Tractive Method.—This method, also known as the "permeameter method," is described in many text-books. The general arrangement is shown in Fig. 14.

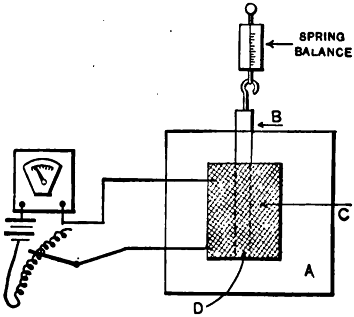


Fig. 14.

A is a rectangular block of soft iron, cut out to receive a magnetizing coil, C, within which is a thin brass tube. The test piece, B, is placed in the tube and makes contact with the block at D, which joint is very carefully surfaced. When a current passes through the magnetizing coil, the test piece adheres tightly to the block at D. The force which is required to detach the test piece is measured by the spring balance, S, which is carefully graduated and provided with an automatic catch so that the index sets at the highest reading. The force which is required to detach the test piece is a function of the induction across the joint, D.

When the yoke is large in relation to the test rod, the reluctance of the circuit is practically that of the test piece.

$$M = \frac{4\pi NI}{10} = FX = \frac{FL}{\mu A} = \frac{BL}{\mu} = HL.$$

$$\therefore \qquad H = \frac{4\pi NI}{10\,L},$$

where L equals the mean length of the lines of force in the test piece; i.e., the sum of the length of the test piece and the opening in the block, divided by two. If the yoke reluctance cannot be neglected, then a connection has to be applied, for which see treatises on magnetic properties of iron and testing.

As will be noted later, the following relation exists between B, H, the cross-sectional area A, and the force required to detach the test piece.

$$B = 157\sqrt{\frac{W}{A}} + H, \qquad (30)$$

where W is in grammes, and A is in sq. cms.,

or,
$$B = 1317\sqrt{\frac{P}{A_1}} + H, \qquad (31)$$

where P is in pounds, and A_1 is in sq. inches.

While this method is subject to several sources of error, it presents a method which is easy of application, and which will give results sufficiently accurate in magnet design. The joint, D, is in an unfavorable position, and Ewing has proposed that the joint should be in the middle of the core, or bar.

Instead of using the above form of

test piece, the iron may be formed into two semi-circular rings, around which the magnetizing turns are placed, and then the force necessary to separate them is measured. The first method, however, is more accurate.

CHAPTER III.

(a.) MATERIALS OF CONSTRUCTION.

THE materials which enter into the construction of an electromagnet are those of the core, the conductor, the insulation and the frame.

Conductor material.—Copper is the only material which is commercially used as a conductor. It should be soft and have a conductivity of at least 98% of that of pure soft copper. The cross-section of the conductor is not necessarily circular; in many cases wires of a square or rectangular cross-section are used, and these shapes may either be solid or made up of ribbons, and bound together. In cases where heavy currents are to be carried, a stranded conductor can often be advantageously used, on account of the greater facility with which it can be handled and wound. For equal diameters, cables or strands have a conducting area of from 20 to 25 per cent. less than a solid circular conductor.

Insulating material.—Insulating material is employed to prevent leakage and short circuits between adjacent turns and layers, or contact with the frame. The principal properties which an insulating material should possess are, (1) a high insulation resistance, (2) it should not absorb moisture, (3) it should withstand high temperatures without injury, (4) it should not be punctured by high voltages, and (5) it should be chemically inert. It is impossible to find any one substance possessing all of the above properties in combination, and thus the selection of the insulating material has to be judged by the case in hand.

Wire insulation.—The insulation of the wire usually consists of a cotton or silk covering, single, double, or triple, as the case may demand; cotton being the more commonly used. On large sized wires a cotton braid is often used in place of a double cotton covering. For small work such as telephone, telegraph, bell or signal work, single cotton, and on the smaller sizes of wire single or double silk covering is used. If the winding is to be moisture proof it should be thoroughly soaked in shellac and dried, or it may be immersed in hot paraffine or beeswax. Stranded and rectangular windings are generally covered with a cotton tape and shellaced after winding.

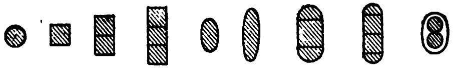
Layer insulation.—In small electromagnets there is little need for insulation between the layers. Where high voltages are employed, oiled linen, vulcanized fibre, or mica should be used. If the core and heads of the electromagnet are of metal they should be covered with some good insulating paint, or the core covered with hard rubber or vulcanized fibre. Mica, vulcanized fibre, oiled or paraffined paper, etc., should be placed between the frame heads and the winding.

When a magnet is to be highly heated and there is danger of the insulation becoming carbonized, asbestos or special fire-proof paints should be used.

Frame.—The material of the coil frame depends upon the character of the magnet, according to the special requirements of the case, as to mechanical strength, cost, etc. Wood, hard rubber, vulcanized fibre, etc., can be used in small magnets, while brass may be used in large ones.

Core material.—Iron and steel are solely used as a core material and their properties have been discussed in another place.

Form of cross-section of magnet core.—The best form of magnet core is that which possesses the smallest circumference for a given area. The following table gives the circumferences for unit areas and the relative circumferences for equal areas :



Description.	Circumference for Unit Area.	Relative Circumfer'ce Circle = 1.
Circle.	3.545	1.00
Square.	4.000	1.13
Rectangle 1:2	4.243	1.20
Rectangle 1:3.	4.620	1.30
Ellipse 1:2.	3.87	1.09
Ellipse 1:3.	4.35	1.28
Oval 1 sq. 2 semicircles.	3.85	1.08
Oval 2 sq. 2 semicircles.	4.28	1.21
2 circles, wire around both, as indicated by dotted lines.	4.10	1.13

From this table it is seen that the circle gives the most economical form of cross-section of core, as less copper is required per convolution of conductor. Circular cores are also of advantage, as leakage from core to core is, for equal mean-distances apart, proportional to the surface of the core, and the circular core has the minimum surface for equal areas. In circular cores all sharp edges are avoided and leakage is minimized.

Thickness of wire insulation.—The thickness of insulation employed upon wires varies with the manufacturer and no fixed value can be given to cover all cases. The following table represents the practice of several large manufacturers. To determine the *diameter* of insulated wire add to the *diameter* of the bare wire:

B. & S. Guage.	For Cotton.		For Silk.	
	Single,	Double.	Single.	Double.
0 to 10	7 mils.	14 mils,		
10 to 18	5 "	10 "		
18 up.	4 "	8 "	2 mils.	4 mils.

The following table constructed from Tables XXVI and XCII in Wiener's "Dynamo Electric Machines" gives the ratio of weight between covered and bare wires. It should be noticed that the thickness of insulation given by Wiener is larger than that given in the above table.

TABLE GIVING THICKNESS AND WEIGHT OF INSULATION ON WIRES.

Gauge of Wire.		Diameter of Wire Bare.	Single Cotton Insulation.			Double Cotton Insulation.	
B. W. S.	B. & S.		Thickness of Insulation, inches.	Weight of Covered Wire per pound of Bare Wire.	Ratio of Copper to total volume of Coil.	Thickness of Insulation, inches.	Weight of Covered Wire per pound of Bare Wire.
1	...	.300	....	.....	....	.020	1.0228
...	1	.289	....	.....	....	.020	1.0232
2	...	.284	....	.....	....	.020	1.0233
3	...	.259	....	.....	....	.020	1.024
...	2	.258	....	.....	....	.020	1.024
4	...	.238	....	.....	....	.020	1.025
...	3	.229	....	.....	....	.020	1.0255
5	...	.220	....	.....	....	.020	1.0265
...	4	.204	.012	1.022	.702	.020	1.0285
6	...	.203	.012	1.022	....	.020	1.0286
...	5	.182	.012	1.0227	.69	.018	1.0287
7	...	.180	.012	1.0228	....	.018	1.029
8	...	.165	.012	1.0233	.683	.018	1.032
...	6	.162	.010	1.0224	.697	.018	1.0325
9	...	.148	.010	1.023	.688	.016	1.0315
...	7	.144	.010	1.0232	....	.016	1.0325
10	...	.134	.010	1.0236	.682	.016	1.0355
...	8	.1285	.010	1.024	....	.016	1.0375
11	...	.120	.010	1.025	.669	.016	1.041
...	9	.1144	.010	1.0255	....	.016	1.0435
12	...	.109	.010	1.0266	.66	.016	1.046
...	10	.102	.010	1.0285	.65	.016	1.05
13	...	.095	.010	1.031	.644	.016	1.0555
...	11	.091	.010	1.0325	.637	.016	1.0585
14	...	.083	.007	1.025	....	.016	1.066
...	12	.081	.007	1.0254	.665	.016	1.068
15	*13*	.072	.007	1.028	.65	.016	[illegible]

TABLE GIVING THICKNESS AND WEIGHT OF INSULATION ON WIRES—*Continued.*

GAUGE OF WIRE.		Diameter of Wire Bare.	SINGLE COTTON INSULATION.			DOUBLE COTTON INSULATION.	
B. W. S.	B. & S.		Thickness of Insulation, inches.	Weight of Covered Wire per pound of Bare Wire.	Ratio of Copper to total volume of Coil.	Thickness of Insulation, inches.	Weight of Covered Wire per pound of Bare Wire.
16	...	.065	.007	1.0315	.64	.016	1.086
...	14	.064	.007	1.0325	....	.016	1.088
17	...	.058	.007	1.036	.625	.014	1.086
...	15	.057	.007	1.037	....	.014	1.086
...	16	.051	.007	1.042	.607	.014	1.096
18	...	.049	.007	1.044	....	.014	1.098
...	17	.045	.005	1.0325	.637	.012	1.093
19	...	.042	.005	1.0355	.627	.012	1.098
...	18	.040	.005	1.0375	.628	.012	1.101
...	19	.036	.005	1.043	.607	.005*	1.056
20	...	.035	.005	1.044	.601	.005*	1.06
21	20	.032	.005	1.05	.587	.005*	1.066
22	21	.028	.005	1.06	.546	.004*	1.06
23	22	.025	.005	1.07	.565	.004*	1.07
24	23	.022	.005	1.08	.521	.004*	1.08
25	24	.020	.005	1.088	.503	.004*	1.088
26	25	.018	.005	1.096	.48	.004*	1.096
27	26	.016	.005	1.104	.457	.004*	1.104
28	27	.014	.005	1.1125	.428	.004*	1.1125
29	28	.013	.005	1.1165	.41	.004*	1.1165
30	...	.012	.005	1.1205	.391	.004*	1.1205
...	29	.011	.005	1.1245	.371	.004*	1.1245

* *Double* silk: 1 mil silk insulation taken equal in weight to 1.25 mil of cotton covering.

(b) FORMULÆ FOR WINDING.

Winding of electromagnets. — The amount of wire which can be wound upon a spool of given volume depends upon the care exercised in the winding to make it uniform, and upon the amount of insulation which is placed between the layers. If V represents the volume of the spool and V_1 the volume of the winding, then $V - V_1$, or $\frac{V}{V_1}$, depends upon the method of winding.

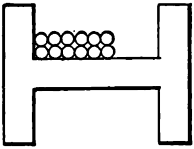


Fig. 15.

Consider the *square* winding, or the layers superimposed as in Fig. 15, and no layer insulation. Then

$$\frac{V_1}{V} = \frac{\text{area circle}}{\text{area circumscribed square}}$$

$$= \frac{\pi}{4} = 0.7854.$$

Consider the *conical* winding, or where the convolutions of one layer fit into the recesses of the lower layer, as in Fig. 16.

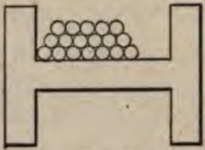


Fig. 16.

Then

$$\frac{V_1}{V} = \frac{\text{area circle}}{\text{area circumscribed hexagon}}$$

$$= \frac{\pi}{\sqrt{12}} = 0.9069.$$

The relation between the volumes occupied in these methods of winding is.

$$\frac{\text{conical}}{\text{square}} = \frac{0.9069}{0.7854} = 1.155,$$

i.e., the conical winding contains about 15 per cent. more wire than the square winding.

In practice something between these extreme cases is obtained.

In the above it is assumed that care is exercised in the winding and that all the layers are uniform. In the case of large magnets the layers can be kept regular and the calculated number of turns per layer easily obtained. In the case of magnets where the smaller sizes of wire are used, difficulty is experienced in making the layers uniform. Paper is inserted at intervals between the layers in order to make a smooth bed for the winding. If care is not taken the winding may become lumpy and considerable volume may thus be lost. Where small wire is used the wire volume on a spool may be much less than even the "square winding" would indicate, on account of the paper, irregularities of insulation, lumpiness, etc.

Formulæ for calculation of windings.—The following notation, as applied to Fig. 17, is hereafter employed unless otherwise specified.

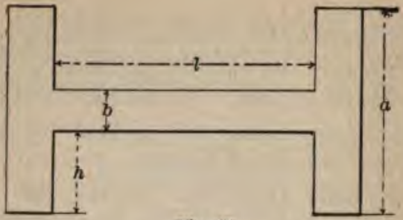


Fig. 17.

D = diameter of covered wire in mils.
d = diameter of bare wire in mils.
t = thickness of insulation on wire in inches, i.e., $\frac{D-d}{2}$.
K = ratio of diameter of insulated wire to bare wire.
a, b, h, and l, as in Fig. 17, in inches.
V = volume of winding space in cubic inches.
N = total number of convolutions on spool.
L = total length of wire on spool in feet.
T = number of layers of wire on spool.
n = number of convolutions per linear inch.

ρ = resistance in international ohms of mil-foot of pure copper wire,
= 10.35 ohms at 20°C. (68°F.).

R = total resistance of coil.

r = resistance per foot of wire in ohms.

$f = \frac{1}{r}$ = feet of wire in one ohm.

l_m = mean length of convolution in inches.

The square winding is to be understood unless otherwise specified.

The *total number of convolutions* of wire of given size, filling a given coil space, is

$$N = 1000000 \frac{lh}{D^2} = \frac{500000\, l(a-b)}{D^2}$$

$$= \frac{500000\, l(a-b)}{K^2 d^2}. \qquad (32)$$

The *diameter* of wire necessary to fill a given coil space with a given number of convolutions, is

$$D = \sqrt{\frac{1000000\, lh}{N}} = \sqrt{\frac{500000\, l(a-b)}{N}}. \qquad (33)$$

or,

$$d = \sqrt{\frac{1000000\,lh}{K^2N}} = \sqrt{\frac{500000\,l(a - b}{K^2N}}$$

(3

The *total length* of wire of given dia
eter which can be wound in a given c
space is

$$L = \frac{65450\,l(a^2 - b^2)}{D^2}. \qquad (3$$

From this formula the dimensions
a spool to hold a specified length of wi
of given diameter may be determined.

If a and b are known,

$$l = \frac{LD^2}{65450\,(a^2 - b^2)}. \qquad (3$$

If b and l are known,

$$a = \sqrt{\frac{D^2L + 65450\,lb^2}{65450\,l}}. \qquad (3$$

If a and l are known,

$$b = \sqrt{\frac{65450\,la^2 - D^2L}{65450\,l}}. \qquad (3$$

The resistance of a given length of copper wire is

$$R = \frac{L\rho}{d^2}. \qquad (39)$$

Substituting the value of L, as given in Eq. (35), and $\rho = 10.35$.

$$R = \frac{677400(a^2 - b^2)l}{D^2 d^2}. \qquad (40)$$

Now $$(a^2 - b^2)l = \frac{4V}{\pi}.$$

Substituting and reducing,

$$R = \frac{862500\ V}{D^2 d^2}. \qquad (41)$$

If the volume of wire is increased ten per cent to allow for the layers fitting into one another, the above formula (41) becomes

$$R = \frac{948700\ V}{D^2 d^2}. \qquad (42)$$

Hence, the diameter of wire necessary

to fill a given volume with a given resistance, is

$$d^4 = \frac{948700\ V}{K^2 R}. \qquad (43)$$

Formulæ (41), (42), and (43) are general whatever the shape of the spool, i.e. whether the core is of circular, square, rectangular, elliptical, etc., cross-section.

The next smaller guage number than the diameter corresponding to the formula should be used in order to allow for irregularities in winding and for insulation between the layers.

The deduction of the above formulæ are based upon the assumption that the temperature of the wire is 20°C. (68°F.). If the coil is to be used at some temperature other than 20°C., a new value of R, i.e., R^1 must be used where

$$R^1 = R\,(1 + 0.004\,\theta_c) \qquad (44)$$

where R^1 is the resistance of the heated wire, R the resistance at 20°C. and θ_c the degree rise in temperature above 20°C.

Or, $$R^1 = R\,(1 + 0.0022\,\theta_f) \qquad (45)$$

where R is the resistance at 68°F., and θ_f the degree rise in temperature above 68°F.

Table IV in Appendix gives the temperature coefficient for copper wire at various temperatures.

A formula known as Brough's Formula* is often applicable to the calculation of the diameter of wire necessary to give a stated resistance. The constant given for circular core differs from that given in Thompson's Electromagnet, p. 210, in that the diameter of the wire and thickness of insulation are taken in mils instead of in thousandths of an inch.

For circular cores. From (40)

$$R = \frac{677400\,(a^2 - b^2)l}{D^2 d^2}.$$

$$D = d + 2t.$$

$$\therefore \quad d^2(d + 2t)^2 = \frac{677400\,(a^2 - b^2)l}{R}.$$

---

* Journal Society Telegraph Engineers. Vol. V., p. 256.

Solving

$$d = \left[\sqrt{\frac{677400\,(a^2 - b^2)l}{R}} + t^2\right.$$

For square cores, as in Fig. 1
(41),

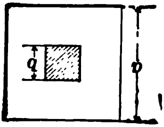


Fig. 18.

$$R = \frac{862500\,l(a^2 - b^2)}{D^2 \times d^2}.$$

$$\therefore\ d = \left[\sqrt{\frac{862500\,(a^2 - b^2)l}{R}} + t^2\right.$$

For rectangular cores, as in Fi

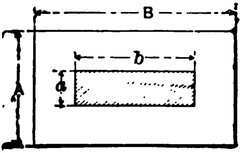


Fig. 19.

$$R = \frac{431250\,(A - a)\,(A + B + a + b)}{D^2 \times d^2}. \quad (46)$$

$$\therefore \quad d =$$

$$\left[\sqrt{\frac{431250\,(A - a)\,(A + B + a + b)}{R}} + t^2\right]^{\frac{1}{2}} - t. \quad (47)$$

For core made up of square and two semicircles, as in Fig. 20,

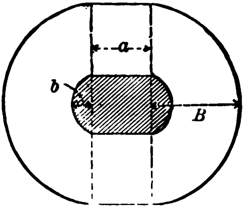


Fig. 20.

$$R = \frac{862500\,(B - b)\,[\pi(B + b) + 2a]}{D^2 \times d^2}. \quad (48)$$

$$\therefore \quad d =$$

$$\left[\sqrt{\frac{862500\,(B - b)\,[\pi(B + b) + 2a]}{R}} + t^0\right]^{\frac{1}{2}} - t. \quad (49)$$

Relation of ampere-turns to dimensions of coil.—

l_m = mean length of turn.

$\therefore$ Nl_m = total length of wire.

$$R = \frac{Nl_m\rho}{12d^2}.$$

$$R^1 = R(1+0.004\theta_c) = \frac{Nl_mP}{12d^2}(1+0.004\theta_c).$$

By Ohm's law $I = \frac{E}{R^1}$.

$$NI = \frac{NE}{R^1}.$$

$$\therefore \quad NI = \frac{NE \times 12d^2}{Nl_m\rho(1+0.004\,\theta_c)}$$

$$= 1.159\,\frac{Ed^2}{l_m(1+0.004\,\theta_c)}. \qquad (50)$$

i.e., the ampere turns are independent of the length of the coil, of the thickness of insulation and of the method of winding; depending upon the diameter of the wire, the mean length of a turn, and the temperature of the coil.

To keep the number of ampere-turns constant in a coil of given volume, d^2 (or the area) of the wire must vary inversely as E.

Given the ampere-turns to find the diameter of wire.—From (50),

$$d^2 = \frac{0.8625\,(\mathrm{NI})\ (1 + 0.004\,\theta_c)l_m}{\mathrm{E}}. \qquad (51)$$

If the potential across the terminals of the coil is known, an approximate value of d can be determined from an approximate value of l_m; then d and l_m may be adjusted to bring them within the required limits.

Instead of finding the diameter of the wire it is often more convenient having

Given the ampere-turns to find the feet per ohm.—From (50),

$$\frac{d^2}{\rho} = \frac{(\mathrm{NI})l_m(1 + 0.004\,\theta_c)}{12\,\mathrm{E}},$$

$$\mathrm{R}_1 = \frac{\mathrm{L}\rho(1 + 0.004\,\theta_c)}{d^2}.$$

$$\frac{d^2}{\rho(1 + 0.004\,\theta_c)} = \frac{L}{R_1} = f_\theta = \text{feet per ohm}$$

at temperature $(\theta_c + 20)^\circ$.

$$\therefore \qquad f_\theta = \frac{(NI)l_m}{12\,E}. \qquad (52)$$

The feet per ohm must be at the final temperature of the coil. Reference to the resistance tables in the Appendix gives the diameter of wire corresponding to the feet per ohm for various temperatures. The next smaller gauge number should be taken.

Curves which show the relation between the ampere-turns, feet per ohm, mean length of turn, etc., for different voltages, can be easily constructed and furnish a graphical means of determining the constants of a coil.*

Density of current in coil.—The current density in the wire, or the density per square inch, is the current in amperes divided by the cross-sectional area of the conductor. The lower the current density the deeper the winding for a given rise of temperature. For coils not exceeding one-half inch thick S. P. Thompson * states that a current density of 3000 amperes per sq. inch can safely be employed. A coil may be designed to give proper current density by proper proportioning of the size of wire.

---

* H. H. Wood. Elec. World, Vol. XXV, 1895, pp. 503, 509.

Heating of magnet coils.—If in a given coil the space taken up by the insulation and the interstices has a fixed ratio to the cross-section of the wire, the magnetizing action and the heating effect remain constant as long as the current remains proportional to the cross-sectional area of the wire; i.e., as long as the current density is constant.

The magnetizing force is proportional to the ampere-turns, i.e., to NI. N varies inversely and I directly as the cross-sectional area of the wire, or,

$$NI \propto \frac{1}{d^2} \times d^2 ;$$

---

* S. P. Thompson "The Electromagnet," 2nd ed. p. 197.

i.e., NI is a constant for a given volume. The heating effect is equal to RI^2. R varies inversely as the square of the cross-sectional area and I directly as the cross-sectional area of the wire, or,

$$RI^2 \propto \frac{1}{d^4} \times d^4 ;$$

i.e., RI^2 is a constant for a given volume.

If the current in a given coil is increased the heat effect increases much more rapidly than the magnetizing force, and thus it is the heating effect which in reality determines the dimensions of the wire to be used.

The heat generated in a magnet coil is conducted to the outside of the coil, to the core, and to the heads of the magnet spools. For practical purposes the supposition is generally made that the heat is radiated from the outside or cylindrical surface of the coil. The practical rule determining the area of radiating surface is to allow from 2.0 to 2.5 square inche per watt lost in the coils for a maximu

Esson's* rule for the increase of temperature of magnet coils is

$$\text{Degrees (centigrade)} = 355\,\frac{W}{S}, \qquad (53)$$

where W = watts lost, and S = superficial area in sq. cms.; or,

$$\text{Degrees (Fahrenheit)} = 100\,\frac{W}{S_1}, \qquad (54)$$

where S_1 = superficial area in sq. inches.

Esson states that this rule can be used for all cases in which the coils do not exceed $2\frac{1}{2}''$ or $3''$ in thickness.

It is known that the region of highest temperature lies somewhere in the interior of the coil and that about 65 per cent of the heat developed is radiated from the outer surface of the coil. Carhart's modification of Esson's rule gives†

$$t_0(\text{C.}) = 500\,\frac{W}{S}, \qquad (55)$$

and

$$t_0(\text{F.}) = 140\,\frac{W}{S_1}. \qquad (56)$$

---

* Jour. Inst. of Elec. Engrs., Feb. 20, 1890.

† Carhart. Electrical World, 1897, Vol. XXIX, p. 11.

This modification allows about 2 sq. in. per watt for 75° F. rise in temperature.

Carhart has given a provisional empirical formula for the maximum temperature of a coil as

$$T_1 = t + 0.0000445\, d^2 \times D$$

where T_1 is the highest temperature (C.°) when depth of coil is not less than $\frac{3}{4}''$, t is temperature of air (C.°), d is current density, and D is depth of coil (inches).

When a coil carries a large current the wire must be of considerable diameter to avoid undue loss of energy in the coils and excessive heating. On the basis above assumed

$$I^2R = 0.5\, S_1,$$

where S_1 is in square inches. The maximum current which can then be safely used in a coil of given resistance and surface is

$$I = 0.7 \sqrt{\frac{S_1}{R}}. \qquad (57)$$

In the case of a shunt coil, the maximum safe voltage is

$$E = 0.7 \sqrt{S_1 R.} \qquad (58)$$

The energy loss being fixed by the temperature increase, the working resistance of the magnet winding can be obtained by means of Ohm's law.

$$R = \frac{E}{I} = \frac{E \times I}{I^2} = \frac{W}{I^2}, \qquad (59)$$

or $$R = \frac{E}{I} = \frac{E^2}{E \times I} = \frac{E^2}{W}. \qquad (60)$$

The first relation applies to the case of constant current working, while the second applies to constant potential working.

Permissible amperage and permissible depth of winding. — The following formulæ give the permissible amperage for coils of stated dimensions.

Watts = I^2R.

w = watts per square inch of cylindrical surface.

A = area in square inches.

$$I = \sqrt{\frac{12\,d^2w}{n\mathrm{T}\rho}}. \qquad (61)$$

Take air at 20° C. (68° F.), and a rise 40° C. (72° F.) gives final temperature f 60° C. (140° F.),

$\rho = 9.612 \times 1.25 = 12.015.$
$w = 0.4$ watt per sq. inch.

Substituting in (61) we have,

$$I = \sqrt{\frac{0.4d^2}{n\mathrm{T}}}. \qquad (62)^*$$

The following tables are derived by means of this formula. For permissible depth of winding 15 per cent is allowed for imbedding of the wires.

---

* Dix, W. S., Elec. Eng., Vol XIV., 1892.

PERMISSIBLE AMPERAGE AND PERMISSIBLE DEPTH OF WINDING FOR MAGNETS WITH DOUBLE COTTON-COVERED WIRE.

GAUGE.		Diam. Bare, inches.	Circular Mils.	Turns per linear inch.	LAYERS.							
					1		5		10		20	
B. & S.	Bir.				Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.
..	2	.284	80656	3.36	97.8	.298	43.7	1.334	31.0	2.63	21.9	5.23
..	3	.259	67081	3.66	85.4	.273	38.1	1.222	27.1	2.41	19.1	4.79
2	..	.2576	66373	3.68	84.6	.2716	37.7	1.216	26.8	2.40	18.9	4.76
..	4	.238	56644	3.97	75.4	.252	33.6	1.128	23.9	2.21	16.8	4.42
3	..	.2294	52634	4.11	71.5	.2434	31.9	1.090	22.7	2.15	16.0	4.27
..	5	.22	48400	4.27	67.2	.234	30.0	1.046	21.3	2.07	15.0	4.10
4	..	.2043	41743	4.58	60.3	.2183	26.9	.980	19.1	1.93	13.5	3.84
..	6	.203	41209	4.61	59.8	.217	26.7	.974	18.9	1.92	13.4	3.80
5	..	.1819	33102	5.10	50.8	.196	22.7	.880	16.1	1.73	11.4	3.44
..	7	.18	32400	5.16	50.0	.194	22.3	.871	15.8	1.71	11.2	3.40
..	8	.165	27225	5.59	44.1	.179	19.7	.804	13.9	1.58	9.85	3.14
6	..	.162	26251	5.68	42.9	.176	19.1	.791	13.6	1.55	9.61	3.09
..	9	.148	21904	6.17	37.6	.162	16.8	.727	11.9	1.43	8.41	2.84
7	..	.1443	20817	6.32	36.2	.1583	16.1	.712	11.5	1.40	8.10	2.78
..	10	.134	17956	6.76	32.5	.148	14.5	.665	10.3	1.31	7.27	2.59
8	..	.1285	16510	7.02	30.6	.1425	13.6	.640	9.70	1.26	6.84	2.50
..	11	.12	14400	7.46	27.7	.134	12.3	.602	8.78	1.18	6,20	2.35
9	..	.1144	13094	7.79	25.7	.1284	11.5	.577	8.14	1.13	5.75	2.25

Permissible Amperage and Permissi
Single Cott

Gauge.		Diameter Bare, inches.	Circular Mils.	Turns per linear inch.	Layers.					
					1		2		4	
B. & S.	Bir.				Amp.	Depth.	Amp.	Depth.	Amp.	
..	2	.284	80656	3.44	96.7	.291	68.3	.56	48.4	1.
..	3	.259	67081	3.76	84.3	.266	59.6	.50	42.2	.
2	..	.2576	66373	3.78	83.6	.2646	59.1	.50	41.8	.
..	4	.238	56644	4.08	74.3	.245	52.5	.46	37.1	.
3	..	.2294	52634	4.23	70.4	.2364	49.8	.44	35.2	.
..	5	.22	48400	4.41	66.2	.227	46.8	.43	33.1	.
4	..	.2043	41743	4.73	59.3	.2113	41.9	.40	29.6	.
..	6	.203	41209	4.76	58.8	.210	39.5	.39	29.9	.
5	..	.1819	33102	5.29	49.9	.189	35.3	.36	24.9	.
..	7	.18	32400	5.35	49.1	.187	34.7	.35	24.5	.
..	8	.165	27225	5.81	43.2	.172	30.5	.32	21.6	.
6	..	.162	26251	5.92	42.1	.169	29.7	.32	21.1	.
..	9	.148	21904	6.45	36.8	.155	26.0	.29	18.4	.
7	..	.1443	20817	6.61	35.4	.1513	25.0	.28	17.7	.
..	10	.134	17956	7.09	31.7	.141	22.4	.26	15.8	.
8	..	.1285	16510	7.38	29.9	.1355	21.2	.25	14.9	.
..	11	.12	14400	7.87	27.0	.127	19.1	.24	13.5	.
9	..	.1144	13094	8.24	25.1	1214	17.8	.23	12.57	.
..	12	.109	11881	8.62	23.4	.116	16.6	.22	11.70	.
10	..	.1019	10382	9.18	21.3	.1089	15.1	.204	10.63	.
..	13	.095	9025	9.80	19.2	.102	13.56	.191	9.60	.
11	..	.0907	8234	10.24	17.9	.0977	12.65	.182	8.95	.
..	14	.083	6889	11.36	15.37	.088	10.85	.165	7.68	.
12	..	.0808	6530	11.66	14.93	.0858	10.55	.161	7.46	.
13	15	.072	5184	12.99	12.61	.077	8.92	.144	6.30	.
..	16	.065	4225	14.29	10.84	.07	7.66	.131	5.42	.
14	..	.0641	4107	14.47	10.63	.0691	7.52	.129	5.31	.
15	..	.0571	3257	16.10	8.98	.0621	6.34	.116	4.49	.
16	..	.0508	2583	17.92	7.58	.0558	5.36	.105	3.79	.
17	..	.0453	2048	19.88	6.41	.0503	4.53	.094	3.21	.
18	..	.0403	1624	22.08	5.41	.0453	3.82	.085	2.71	.
19	..	.0359	1288	24.45	4.59	.0409	3.24	.077	2.29	.
20	21	.032	1024	27.03	3.88	.037	2.74	.069	1.94	.
21	..	.0285	810	29.85	3.28	.0335	2.32	.063	1.64	.
22	..	.0253	642	33.00	2.79	.0303	1.97	.057	1.39	.
23	..	.0226	509	36.23	2.37	.0276	1.67	.052	1.184	.
..	24	.022	484	37.04	2.29	.027	1.616	.051	1.142	.
24	..	.0201	404	39.84	2.01	.0251	1.420	.047	1.005	.
25	..	.0179	320	44.64	1.69	.0224	1.193	.042	.845	.
26	..	.0159	254	49.02	1.436	.0204	1.014	.038	.718	.
27	..	.0142	201	53.48	1.223	.0187	.865	.035	.611	.
28	..	*.0126*	159.8	58.48	1.043	.0171	.737	.032	.521	.
29	..	*.0113*	126.7	63.29	.893	.0158	.631	.030	.446	.
30	..	*.01003*	100.5	68.97	.762	.0145	.538	.027	.381	.

DEPTH OF WINDING FOR MAGNETS WITH COVERED WIRE.

LAYERS. 6		8		10		12		16	
Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.	Amp.	Depth.
39.5	1.55	34.2	2.06	30.7	2.57	27.9	3.08	24.2	4.08
34.4	1.42	29.8	1.89	26.7	2.35	24.3	2.81	21.1	3.74
34.1	1.41	29.6	1.87	26.5	2.34	24.1	2.80	20.9	3.72
30.3	1.31	26.1	1.74	23.6	2.16	21.4	2.59	18.6	3.44
28.8	1.26	24.9	1.67	22.3	2.09	20.3	2.50	17.6	3.32
27.0	1.21	23.4	1.61	21.0	2.00	19.1	2.40	16.6	3.19
24.2	1.13	21.0	1.50	18.8	1.86	17.1	2.23	14.8	2.97
24.0	1.12	20.8	1.49	18.6	1.85	16.9	2.22	14.7	2.95
20.4	1.01	17.7	1.34	15.8	1.67	14.4	2.00	12.5	2.86
20.0	1.00	17.3	1.33	15.5	1.65	14.1	1.98	12.27	2.63
17.6	.92	15.3	1.22	13.7	1.52	12.5	1.82	10.80	2.42
17.2	.90	14.9	1.20	13.3	1.49	12.1	1.79	10.52	2.38
15.0	.83	13.0	1.10	11.65	1.37	10.6	1.64	9.20	2.18
14.4	.81	12.5	1.07	11.21	1.33	10.2	1.60	8.85	2.13
12.9	.75	11.2	1.02	10.04	1.24	9.15	1.49	7.92	1.98
12.2	.72	10.6	.96	9.48	1.20	8.63	1.43	7.47	1.90
11.0	.68	9.56	.90	8.56	1.12	7.79	1.34	6.75	1.79
10.2	.65	8.90	.86	7.95	1.07	7.25	1.28	6.27	1.71
9.55	.62	8.28	82	7.44	1.02	6.75	1.23	5.85	1.63
8.20	.58	7.54	77	6.75	.96	6.15	1.15	5.32	1.53
7.84	.55	6.80	72	6.08	90	5.54	1.08	4.80	1.43
7.31	.57	6.34	69	5.67	.86	5.17	1.03	4.97	1.37
6.27	.47	5.44	62	4.87	78	4.43	.93	3.84	1.24
6.10	.46	5.28	.61	4.73	.76	4.31	.91	3.73	1.21
5.15	.41	4.47	.55	4.00	.68	3.64	.82	3.15	1.08
4.43	.38	3.84	.50	3.44	.62	3.12	.74	2.71	.98
4.34	.37	3.76	.49	3.37	.61	3.07	.73	2.66	.97
3.66	.33	3.18	44	2.85	.55	2.59	.66	2.24	.87
3.10	.30	2.68	.40	2.40	.49	2.19	.59	1.89	.79
2.62	.27	2.27	.36	2.08	.44	1.85	.53	1.60	.74
2.21	.24	1.91	.32	71	.40	1.56	.48	1.35	.64
1.87	.22	1.62	29	.46	.36	1.32	.43	1.15	.58
1.58	.198	1.37	.26	.26	.33	1.12	.39	.970	.52
1.34	.179	1.16	.24	1.04	.30	.946	.35	.820	.47
1.14	.162	.988	.22	.885	.27	.805	.32	.697	.43
.968	.148	.839	.20	.752	.24	.683	.29	.592	.39
.935	.144	.810	.19	.726	.21	.661	.29	.572	.38
.820	.134	.712	.178	.637	.22	.580	.27	.502	.35
.690	.120	.598	.159	.536	.197	.487	.24	.322	.32
.587	.109	.508	.145	.455	.180	.411	.21	.309	.29
.499	.100	.433	.133	.388	.165	.353	.198	.306	.26
.427	.092	.369	.121	.331	.151	.302	.181	.261	.24
.364	.085	.316	.112	.283	.139	.258	.167	.223	.22
.311	.078	.270	.103	.242	.128	.220	.153	.190	.20

Weight of magnet winding in terms watts lost in winding.—The resistance a mil-foot of copper wire at a tempe ture of 20° C. (68° F.) is 10.35 ohms a the weight of 1000 feet is 0.00303 lbs.

$$R = \frac{10.35\,L}{d^2}.$$

The weight of a wire in pounds (W

$$W = \frac{L}{1000} \times 0.00303\, d^2.$$

$$\therefore \qquad d^2 = \frac{1000\,L}{0.00303\,W}.$$

$$\therefore \qquad R = \frac{10.35\,L^2 \times 0.00303}{1000\,W}.$$

$$R = \frac{E}{I} = \frac{\text{watts}}{I^2}.$$

$$\text{watts} = \frac{10.35\,L^2 \times 0.00303\,I^2}{1000\,W}.$$

$$\text{or,} \qquad W = \frac{31.4\,L^2 I^2}{(1000)^2\,\text{watts}}. \qquad ($$

L, the total length of wire, is equa

the mean turn times the number of turns, and LI equals the product of the ampere-turns and the mean length of one turn.

$$\therefore \quad \text{weight of winding (lbs.)} =$$

$$\frac{31.4\left[\dfrac{\text{ampere turns} \times \text{feet per turn}}{1000}\right]^2}{\text{watts lost in winding}}. \quad (64)$$

This formula can be worked backwards to find the size of wire to be used, but allowance for increased resistance due to heating must be made if necessary. The weight of wire can be found that gives a fixed magnetizing force with a definite loss of energy in the winding.

Relations holding between constants of coils.—In the following it is considered that the thickness of the wire insulation is proportional to the diameter of the wire and that all coils are uniformly wound. The results obtained under these considerations are practically but not strictly correct.

It follows directly that *the weight of copper required to fill a given coil volume* *is constant whatever the size of the wire used.*

From (41) the equation

$$R = \frac{862500\,V}{D^2 d^2} \text{ may be written,}$$

$$R = \frac{A}{d^4}, \text{ where A is a constant as V}$$

is a constant, and $D = Kd$.

It follows directly that *the resistance of a given coil varies inversely as the fourth power of the diameter of the wire used*, or, as the cross-sectional area varies as d^2, *the resistance of a given coil varies inversely as the square of the cross-sectional area of the wire used.*

From equation (32) on page 71,

$$N = \frac{500000\,l(a-b)}{K^2 d^2} = \frac{B}{d^2},$$

where B is a constant for fixed volume. It follows directly that *the number of turns in a fixed volume varies inversely as the square of the diameter of the wire* *used,* or *inversely as the cross-sectional area of the wire used.*

From the above relation

$$\frac{1}{d^2} = \frac{N}{B}.$$

Hence by substitution,

$$R = \frac{A}{d^4} = \frac{AN^2}{B^2} = cN^2,$$

where c is a constant for fixed volume. It follows directly that *the resistance of a coil varies directly as the square of the number of turns.*

The magnetic effect produced by an electromagnet of given size, shape and construction is proportional to the product of the current into the square root of the resistance of the coil; i.e., magnetic effect or ampere turns varies as $I\sqrt{R}$. Ampere-turns equals NI and as R varies as N^2, N varies as $\sqrt{R}$ and hence NI varies as $I\sqrt{R}$.

If a given coil is wound to a resistance R with a wire of diameter d, what diameter of wire shall be used to rewind to a resistance R_1?

$$R \text{ varies as } \frac{1}{d^4}, \text{ i.e., } R = \frac{A}{d^4};$$

for same volume, $$R_1 = \frac{A}{d_1^4},$$

therefore, $$\frac{R}{R_1} = \frac{d_1^4}{d^4},$$

or, $$d_1^4 = \frac{R}{R_1} d^4. \tag{65}$$

If two coils of the same dimensions are wound with different sized wire, the current must vary with the cross-sectional area of the wire, that is, current density must be the same in each, in orde to obtain the same heating effect c the same temperature rise.

For $$R = \frac{A}{d^4}.$$

$$\text{Heat loss} = I^2R = \frac{AI^2}{d^4} = A_1 \frac{I_2}{\text{area}^2}$$

$$= A_2 (\text{density})^2 \cdot$$

Hence, for same energy loss the density must be a constant.

Also,

$$\text{Heat loss} = \frac{E^2}{R} = \frac{E^2 d^4}{A} = \frac{E^2 (\text{area})^2}{A_1}.$$

Hence, for same energy loss, E^2 must vary inversely as the $\overline{\text{area}^2}$, or for same heating effect, the voltage across terminals of coil must vary inversely as the cross-sectional area of the wire used.

Relation of resistance of magnet winding to resistance of external circuit.—An electromagnet is connected to a circuit at the further end of which an E.M.F. is applied; what is the best resistance to give the electromagnet in order to get the maximum magnetic effect?

Let B represent the battery resistance, and R the resistance of the electromagnet, and R_0 the resistance of the rest of the circuit. The resultant current is

$$I = \frac{E}{(B + R_0) + R}.$$

The magnetic effect produced by a current I, is proportional to I $\sqrt{R}$, or equal to KI $\sqrt{R}$, where K is some constant. Therefore,

$$\text{magnetic effect} = \frac{KE}{\frac{B + R_0}{\sqrt{R}} + \sqrt{R}},$$

and is a maximum when the denominator has a minimum value, i.e., when

$$\frac{B + R_0}{\sqrt{R}} = \sqrt{R}, \text{ or, } (B + R_0) = R, \qquad (66)$$

that is, the electromagnet should have a resistance equal to that of the rest of the circuit. It has been proved by Ayrton and Whitehead* that in the case of a leaky telegraph line, the resistance of the magnet, A, should equal the apparent resistance of the line tested from the A end, when the further, or B, end is grounded through the apparatus at that end.

It must be noted, however, that while

---

* Journal Inst. of Elec. Eng. Vol. XXIII., 1894, p. 327.

the above solution applies to a permanent state of current, it does not apply to a variable state of current in general, notably that in the case of rapid telegraphy.*

While not following the above deduction absolutely in practice, the guiding factor is that, if working through a low resistance line, a low resistance battery and magnet coil should be used ; while if working through a high resistance line, a high resistance coil must be used in connection with a battery of high E.M.F.

---

* Discussion of Ayrton & Whitehead's Paper by Prof, Hughes.

Vaschy, "Electricité et Magnetisme," Tome II. p. 32.

CHAPTER IV.

In the application of electromagnetism there are many forms of apparatus or mechanisms; some for the consumption of large amounts of energy, such as field magnets, magnets for lifting purposes, etc.; and then those in which only a small amount of energy is consumed, such as those in which a relative motion of parts is produced, as in measuring instruments, relays, bells, telephone receivers, etc.

In all forms of electromagnets the action is based upon the principle of "least reluctance;" that is, the magnetic circuit tends to set itself so that its reluctance reaches a minimum value. The general principle of most electromagnetic mechanisms is the tendency to shorten or close the magnetic circuit by the attraction, or insertion, of an armature when the electromagnet is energized.

Electromagnets may be broadly divided into tractive or portative magnets and attractive magnets according to their function.

TRACTIVE ELECTROMAGNETS.

It may be shown that the force which exists between the pole of an electromagnet and the face of the armature or keeper is

$$P\ (\text{dynes}) = \frac{B^2 A}{8\pi}, \qquad (67)$$

where B = induction per sq. cm.
A = area of contact surfaces in cm².

One gramme being equivalent to 981 dynes, approx., (67), reduces to

$$P\ (\text{grammes}) = \frac{B^2 A}{8\pi \times 981} = \frac{B^2 A}{24650}. \qquad (68)$$

or,

$$P\ (\text{kilogrammes}) = \frac{B^2 A}{2465000000}. \qquad (69)$$

$$= \frac{B^2 A}{(5000)^2}, \text{ approximately.}$$

498568

In terms of pounds and sq. cms., (68) becomes

$$P_1 \text{ (lbs.)} = \frac{B^2 A}{11183000}. \tag{70}$$

In terms of pounds and sq. inches, (68) becomes

$$P_1 \text{ (lbs.)} = \frac{B_1{}^2 A_1}{72134000}. \tag{71}$$

$$= \frac{B_1{}^2 A_1}{(8500)^2}, \text{ approximately.}$$

This equation gives the weight which a given area will hold up when a certain induction is passing normally through that area.

Let $p_1 =$ pounds per sq. inch;
then,

$$p_1 = \frac{P_1}{A_1} = \frac{B_1{}^2}{72134000} = \left(\frac{B_1}{8500}\right)^2, \text{approx.,}$$

which is the pounds per sq. inch that a given induction, B_1, will support.

$$F_1 = B_1 A_1. \qquad \therefore\ B_1{}^2 A_1 = \frac{F_1{}^2}{A_1}.$$

Substituting in (71) and rearranging,

$$A_1 = \frac{F_1^2}{72134000\, P_1}, \qquad (72)$$

which is the relation between area, weight to be supported, and total induction.

Also, $$A_1 = \frac{72134000\, P_1}{B_1^2}.$$

From (71), $$B_1^2 = 72134000 \frac{P_1}{A_1}.$$

$$\therefore \qquad B_1 = 8493 \sqrt{\frac{P_1}{A_1}}$$

$$= 8493 \sqrt{\frac{\text{Pull in pounds}}{\text{Area in sq. inches}}}, \qquad (73)$$

which gives the induction per square inch that is necessary to support a given weight over a given area.

Also,

$$B = 1317 \sqrt{\frac{\text{Pull in pounds}}{\text{Area in sq. inches}}}. \qquad (74)$$

$$B = 4965 \sqrt{\frac{\text{Pull in kilos}}{\text{Area in sq. inches}}}. \qquad (75)$$

$$B = 157\sqrt{\frac{\text{Pull in grammes}}{\text{Area in sq. cms.}}}. \qquad (76)$$

Equations (30) and (31) differ from the above (76) and (74) by the addition of the term H on the right-hand side of the equation. The reason for this is, that in the method described on p. 57, the core is moved while the coil is fixed, and hence the pull is that due to B—H lines of force.

By means of equations (68) and (71) the following table has been calculated. (See S. P. Thompsou, "The Electromagnet," p. 119.)

MAGNETIZATION AND TRACTION OF ELECTRO-MAGNETS.

B lines per sq. cm.	B lines per sq. inch.	Grammes per sq. cm.	Kilogs. per sq. cm.	Pounds per sq. inch.
1,000	6,450	40.56	.0456	.577
2,000	12,900	162.3	.1623	2.308
3,000	19,350	365.1	.3651	5.190
4,000	25,800	648.9	.6489	9.228
5,000	32,250	1,014	1.014	14.39
6,000	38,700	1,460	1.460	20.75
7,000	45,150	1,987	1.987	28.26
8,000	51,600	2,596	2.596	36.95
9,000	58,050	3,286	3.286	46.72
10,000	64,500	4,056	4.056	57.68
11,000	70,950	4,907	4.907	69.77
12,000	77,400	5,841	5.841	83.07
13,000	83,850	6,855	6.855	97.47
14,000	90,300	7,550	7.550	113.1
15,000	96,750	9,124	9.124	129.7
16,000	103,200	10,390	10.390	147.7
17,000	109,650	11,720	11.720	166.6
18,000	116,100	13,140	13.140	186.8
19,000	122,550	14,630	14.630	208.1
20,000	129,000	16,230	16.230	230.8

This table is based upon the assumption that there is a uniform distribution of lines of force over the area considered.

On the assumption that there is no magnetic leakage the ampere-turns required for a stated induction are by (22),

$$NI = 0.3132\, F\Sigma \frac{l}{\mu A}$$

where Σ signifies the sum of the reluctances of the different portions of the magnetic circuit.

Assuming that the iron of the different portions of the circuit is of the same magnetic quality, and that there is no magnetic leakage (22) by the relation $F = B_1 A_1$ reduces to

$$NI = 0.3132 \frac{B_1 l_{11}}{\mu} \qquad (77)$$

where l_{11} is the mean total length in inches of the path of the lines of force.

Hence, $$B_1 = \frac{\mu NI}{0.3132\, l_{11}}. \qquad (78)$$

Equating (73) and (74), and reducing

$$NI = 2661 \frac{l_{11}}{\mu} \sqrt{\frac{P_1}{A_1}}, \qquad (79)$$

which gives the total number of ampere-turns necessary when the mean length of the magnetic circuit, weight to be supported, and total area are known.

If the dimensions are given in metric measure,

$$NI = 3951 \frac{l}{\mu} \sqrt{\frac{\text{Pull in kilos.}}{\text{Area in sq. cms.}}}. \qquad (80)$$

In designing a magnet for tractive purposes, certain assumptions have to be made; first, as to the density of the lines of force. The tractive power increases as B^2 and B should be made as large as possible, about 120,000 lines per sq. in., i.e., for wrought iron. The softest wrought iron of the highest permeability should be used. Having fixed on the value of B, the relation given in (69) and (70), between B and P determines A. From the formula it is seen that a large induction is more essential than a large polar area, as the induction enters the formula as the square while the area enters as the first power. The area of cross-section must, however, be as large as possible. The cross-section may be reduced somewhat at the contact-surfaces; this must not be carried too far, however, as it will tend to increase leakage and reluctance. The reluctance of the circuit must be kept as low as possible, therefore the shape must be compact. The contact surfaces must be carefully faced so that the reluctance of the joints will be as small as possible.

ATTRACTIVE ELECTROMAGNETS.

By an attractive electromagnet is understood one in which a relative motion between the component parts takes place when the coil is energized.

The value of the attraction which exists between any two parts of the magnetic circuit, such as the poles and the armature, depends directly upon the area of the attracting surfaces and the square of the magnetic induction, the separation between poles and armature being constant. If the area and the induction are constant, the attraction varies inversely as the square of the distance separating the attractive surfaces. With a constant M.M.F. the attraction decreases rapidly as the separation increases, on account of the increased separation and the greatly decreased induction caused by the increased reluctance of the magnetic circuit due to the air-gap. For a small separation the attraction on the armature is considerable, and hence, the amount of play of the moving part for a given attraction is small and has to be limited. As the armature is attracted the separation decreases and the attraction increases. The force acting on the armature is thus a variable one.

In order to partly overcome the decrease in magnetic flux due to the increased reluctance, the number of ampere-turns, and hence the M.M.F. may be increased by increasing the number of turns in the coil winding. This increases the length of the core, but the increased reluctance due to the increased length is small compared to the air-gap reluctance.

Numerous plans have been devised to increase the play of the armature and to make the attraction more uniform. Only the general methods can be considered here.

The resultant motion may be increased or equalized by mechanical devices, such as levers, toothed wheels, etc., and variations in attraction may be governed by springs.

The play of the armature may be increased by inserting an iron wedge into the magnetic circuit, the wedge, or armature, being so shaped that there is practically a uniform decrease in the reluctance. The armature may be provided with conical projections which work into conical cavities in the core, or the reverse. In the case of light armatures conical projections on the core may fit into conical shaped holes in the armature.

If a considerable displacement is desired with a small variation in the attractive force, the maximum effect is produced by the suction of a core into a solenoid. The field of a solenoid is sensibly uniform in the region of the center and decreases towards the ends where it is weakest owing to the demagnetizing effect of the ends. The magnetic field of a solenoid is not perfectly uniform. The magnetic field produced by the induced poles react and have a demagnetizing action as indicated in Fig. 21.

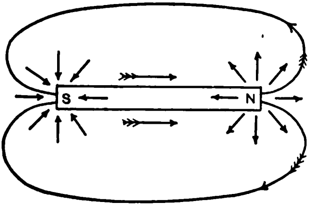


Fig. 21.

The direction of the lines of force produced by the solenoid are indicated by the feathered arrows, and the plain arrows indicate the direction of the lines of force produced by the induced poles, which radiate out from each end. It is seen that in the interior of the solenoid the two sets of lines are opposed, thus producing an unequal distribution of the fields near the ends. This effect is the more marked the shorter the coil or the smaller the ratio of length to diameter. The introduction of an iron core into the solenoid greatly increases this demagnetizing action.

Consider a core several times longer than the solenoid. As the core approaches and enters the solenoid the pole induced at its lower end is attracted and drawn further in. This action by decreasing the reluctance of the circuit increases the flux and therefore the attraction. When the end of the core approaches the end of the solenoid the attraction is at a maximum, and as the end emerges the attraction decreases as the induced pole enters a region where the field intensity is diminishing.

If the core has a length the same as that of the solenoid the action is different, as the repulsive action of the pole induced at the further end of the core plays an important part. In this case the resultant attraction is a maximum when the end reaches the center of the solenoid, then diminishing and becoming zero when the core is symmetrically placed in the solenoid.

The attraction on the core is somewhat more uniform when the entering end of the core is cone-shaped. The maximum attraction is reached when the apex of the core has emerged some distance out of the coil, but is not as great for the cone-shaped core as for the cylindrical core. By giving the core more complicated forms, the attraction can be made more uniform over a longer range, but with a smaller value than with the cylindrical core.

The suction effect can be much increased by using an iron-clad solenoid, as shown in Fig. 22.

The field at the interior of the solenoid is greatly increased, and the pull is made more uniform. There is no external field in this case, and the core is not

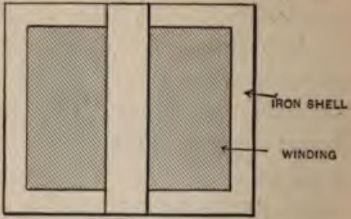


Fig. 22.

attracted until the end is introduced into one of the openings of the shell. Fig. 23

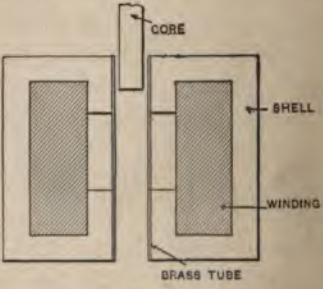


Fig. 23.

shows an extension of the iron-clad type, there being iron tubes extending into the interior. The field is thus concentrated into a short space and a very powerful pull is produced on the iron core, or plunger, through a short distance. The range of action can be varied by increasing or decreasing the length of the internal tubes.

Hollow cores, for weak magnetizing forces, act as well as solid ones, but for strong magnetizing forces solid cores are much superior.

Many modifications of the coil and plunger electromagnet have been made, their construction depending upon their use. The coil may be wound in sections, different sections being connected in different circuits as in a shunt circuit, or a series circuit, etc. The coils may be connected differentially, the attraction then depending upon the difference in current strengths. A form known as the differential coil and plunger has had some use in arc lamp regulation, and is shown in Fig. 24.

Here the action of the plunger deper upon the relative strengths and directi of the current in the two coils. The r chanical action in B is more independe and the magnetization of each plun

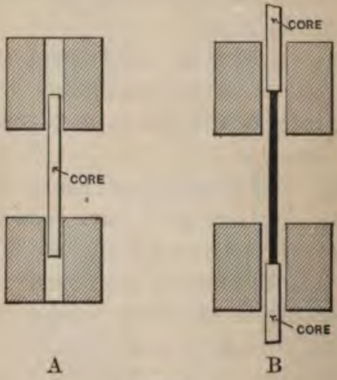


Fig. 24.

is dependent upon the current streng in its own coil.

Fig. 25 shows the use of a differen coil and plunger electromagnet in the f mechanism of an arc lamp, one coil bei connected in series with the carbon c cuit, and the other circuit in shunt with it. In this case when the carbons are in contact the series coil becomes energized and lifts the upper carbon, thus causing some current to flow through the shunt coil, and the extent of separation of the carbons is dependent upon the relative pull of the series and shunt coils.

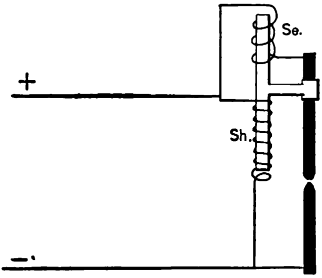


Fig. 25.

A form of magnet which has an extensive range and a powerful pull over a large part of that range, combines the construction of both the core electromagnet and the coil and plunger electromagnet.

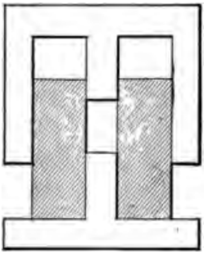


Fig. 26.

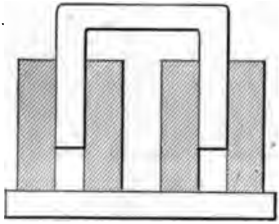


Fig. 27.

Two forms are shown in the Figures 26 and 27.

DESIGN OF TRACTIVE ELECTROMAGNETS.*

An electromagnet performs work when a loaded armature, placed at a given distance from its poles, is attracted and drawn up to the poles. Work done by an electromagnet may be defined as the product of the initial pull exerted upon the armature and the travel of the armature. It may be shown that this product is a maximum when the armature is placed at such a distance from the poles that the ratio of the rate of change of the magnetic flux in the iron to the rate of change of the magnetizing force producing it is equal to the permeance of the working air-gaps.

Let M be the m.m.f. acting on all the circuit except the working air-gap.

---

* W. E. Goldsborough, Elec. World, Vol. XXXVI, p. 125, July 28, 1900. The following pages (117-121) are taken almost literally from this article. For further details, reference should be made to this article. Further see E. R. Carichoff, Elec. World, Vol. XXIII, p. 113 and p. 212 1894. C. T. Hutchinson, Elec. World, Vol. XXIII, p. 243, 1894.

Let M^1 be the m.m.f. acting on the working air-gap.

Then $M + M^1$ is a constant, and equal to the applied m.m.f.

Let F_c be the total magnetic flux in the core of the exciting coil.

Let F be the total magnetic flux in the working air-gap.

Let A^1 be the working area of the air-gap.

Let L be the length of the working air-gap.

Then $$\frac{dF}{dM} = \frac{F}{M^1} = \frac{A^1}{L}, \qquad (81)$$

The meaning of this relation may be better understood by a study of Fig. 28.

The m.m.f. acting on the magnetic circuit is a constant, and the relative values of M and M^1, i.e., of the m.m.f.'s required to force the flux F, through the iron and the air-gap is dependent upon the value of L. The greater L, the greater the value of M; the smaller L, the greater the value of M^1.

The curve OSJ is plotted from the values of the total flux and the corresponding values of the m.m.f. (M) impressed upon all of the magnetic circuit outside of the working air-gap. The curve KTI is plotted from the values of the total flux in the working air-gap and the corresponding values of the m.m.f. (M^1) required to force this flux across the working air-gap. Since $M + M^1$ is a constant the sum of the abscissae of the two curves, taken for successive values of F, will give the straight line K J.

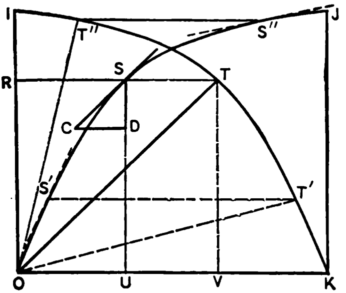


Fig. 28.

The slant of the tangent to the curve OSJ at any point, as S, will graphically represent the ratio $\frac{dF}{dM}$, since SD and CD are respectively proportional to dF and dM. Taking the point T on the curve KTI, that has the same ordinate as the point S, and connect T and O, the line OT will represent the ratio $\frac{F}{M^1}$, since TV and OV are respectively equal to F and M^1.

The excitation remaining constant, as the armature moves up to its seat, the points S and T move along the curves OSJ and KTI, towards J and I, respectively, and when they arrive at such positions that the tangent to the curve at S is parallel to a line connecting O and T the condition expressed by equation (81) is fulfilled, and the armature is in that position which admits of the magnet doing the maximum amount of work. The points S and T will always be opposite one another, and have the same ordinate values.

When the armature is upon its seat, i.e. makes contact with the pole pieces, the points S and T will be at J and I respectively, and the magnet will be exerting its maximum grip upon the plunger or armature. Under these conditions the magnet is capable of sustaining a large weight, and essentially presents all the features of the ordinary portative electro-magnet.

When the armature is removed to a great distance, the points S and T approach the positions O and K, respectively, but owing to the fact that the mean density in the working air-gap can never be reduced to zero, they will stop short of the limits, in some position where but a feeble pull is exerted upon the armature. The action of the magnet upon its armature for points on the curves below the points S and T, as shown, is analogous to the action of an iron-clad solenoid upon its plunger, especially when the electromagnet is of the iron-clad type, and the armature or plunger is conical shaped and works into a conical shaped recess.

ELECTROMAGNETS FOR PRODUCING STRONG FIELDS.

In electromagnets for producing strong fields the magnetic circuit should be relatively short and should be mechanically strong so as to prevent springing by the attraction of the poles under the influence of strong fields.

To produce a strong field it is first necessary to obtain as strong a field as possible by the use of a large number of ampere-turns, and then to use specially formed pole-pieces in order to concentrate the field. In order to obtain intense field pointed pole-pieces have long been used. Theory indicates, and experiment confirms, that a conical pole-piece of 120° aperture gives the maximum field, of say 40,000 lines per sq. cm. over an extent of several square millimeters. The radius of the pole face should be small, about 1.5 m.m.(1)

POLARIZED MECHANISMS.

A form of mechanism in which a permanent magnet is used in addition to an electromagnet has extensive applications in practice, and is known as a polarized mechanism. Such mechanisms are used in telegraphy, as the polarized relay; in telephony, as the polarized bell and telephone receiver; and in many forms of signaling apparatus. This form of mechanism possesses several marked properties as follows.

First. Bilateral Action.—In the ordinary electromagnet, the armature is attracted whatever the direction of the current around the core. If the armature is a permanent, or an induced magnet, the armature is either attracted or repelled according to the direction of current in the coils, as shown in Fig. 29, where the armature is shown pivoted at one end. If the direction of current is as shown the armature is attracted to the left, and if the direction of current is in the opposite direction it is attracted to the right. The direction of deflection is dependent upon the direction of current flow in the coils. If the relation of armature and coils is as shown in Fig. 30, where the polarized armature is pivoted at the centre, so that one end is over each core, the right end is repelled and the left end attracted. Reversing the

---

(1) For further details see Du Bois, loc. cit., p. 258.

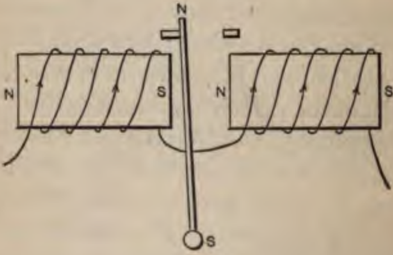


Fig. 29.

direction of current, reverses the attraction and repulsion. If the armature in either case carries a hammer it may be arranged to vibrate against a bell.

The armature in place of being polarized, may be of soft iron, while the cores are polarized. Then one end of the armature is attracted on account of the excess pull which one core possesses over the other, when the coils are energized. Reversing the direction of current, reverses the armature attraction. In case of a single polarized core, as in a telephone receiver, the armature has a zero position, or one of rest, and either approaches or

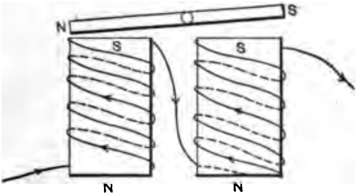


Fig. 30.

recedes from the pole piece according to the direction of current in the coil.

In virtue of this bilateral action an electromagnet is responsive to an alternating current if the inertia of the moving parts is not too great.

Second. Rapidity and sensitiveness of action.—Polarized mechanisms can be worked with great rapidity, as the attractive force of the permanent magnet may be just balanced by a spring, so that with the least addition to the field strength the balance is overcome and the armature moved. In some of the most rapid forms of mechanism, such as the printing telegraph, etc., polarized mechanisms are used.

Greater sensitiveness can also be obtained with weak currents or with small changes of currents. According to the law of traction the force acting on the armature is

$$F = \frac{SB^2}{8\pi}. \qquad (82)$$

for a given separation. For a given separation and area it is proportional to B^2. If the induction is increased by an amount ΔB the pull becomes proportional to $(B + \Delta B)^2$ and the increased pull is proportional to $2B\Delta B + \overline{\Delta B}^2$. As $\overline{\Delta B}^2$ is small compared to $2B\Delta B$, the change in pull is proportional to $2B\Delta B$, that is, the change in pull is proportional to the initial induction as well as to the change in induction, and the greater the initial induction the greater the change in pull due to small change in the induction.

In a telephone receiver the permanent magnet is necessary to keep the pitch of the emitted tone the same as that of the transmitted tone.

Electromagnets for use with currents of brief duration.—In telegraphy, use of the chronograph, signaling apparatus, etc., it is essential that the electromagnet should respond to currents of very brief duration. This is in part accomplished by making the movable parts light and of small inertia, and by placing the armature in a biased position.

The rapidity of working is further dependent upon a property of the electric circuit known as its self-induction or inductance. The magnetic field set up about a conductor during a change of current flow in the conductor, generates an E.M.F. which is in opposition to the E.M.F. producing the current. The coefficient of self-induction may be defined as *the ratio of the number of lines of force linked with a circuit to the current producing them.* If F is the flux produced by unit current, N the number of turns, or convolutions, in the winding, then

$$L = FN. \qquad (83)$$

The *henry* is the practical unit of inductance and is 10^9 times the C.G.S. unit of inductance.

Then $$L = \frac{FN}{10^9} \text{ henrys.} \qquad (84)$$

In any magnetic circuit, where I is in amperes,

$$F = \frac{\frac{4\pi}{10} NI}{\Sigma \frac{l}{A\mu}}. \qquad (85)$$

Therefore

$$L = \frac{4\pi N^2 \Sigma \frac{A\mu}{l}}{10^9} \text{ henrys.} \qquad (86)$$

The inductance varies directly as the square of the number of turns in the winding and directly as the permeability of the magnetic circuit. As the permeability varies with the magnetizing current it is impossible to calculate exactly the value of L from the dimensions of the circuit. If the working value of I is known, a value of μ may be approximated, and comparative values of L may be thus obtained. For exact work L must be measured under working conditions.

When a circuit containing inductance is closed the current does not instantly rise to its full value, but lags behind as if possessing inertia. The law which expresses the strength of current in a circuit at a time t after the closing of the circuit is

$$i_t = \mathrm{I}\left(1 - e^{-\frac{\mathrm{R}t}{\mathrm{L}}}\right) = \frac{\mathrm{E}}{\mathrm{R}}\left(1 - e^{-\frac{\mathrm{R}t}{\mathrm{L}}}\right) \quad (87)$$

where i_t stands for the current strength at time t (seconds), I, E, R and L have their usual meaning, and e is the number 2.7183. The ratio $\frac{\mathrm{L}}{\mathrm{R}}$ is known as the time constant of the circuit, and is usually denoted by the letter T. Then

$$i_t = \mathrm{I}\left(1 - e^{-\frac{t}{\mathrm{T}}}\right) = \frac{\mathrm{E}}{\mathrm{R}}\left(1 - e^{-\frac{t}{\mathrm{T}}}\right). \quad (88)$$

At the instant of closing the circuit $t = o$ and therefore $i_t = o$. When $t = \mathrm{T}$, $i_t = \mathrm{I}\left(\frac{e-1}{e}\right) = 0.632\mathrm{I}$. The time-constant of a circuit can then be defined as the time from closing the circuit in which the current rises to 0.63 times its maximum, or Ohm's law value.

The time-constant may be reduced by decreasing L, or increasing R, or both. In a coil of given volume, the inductance and resistance are both proportional to the square of the number of turns, so that the time-constant of a given coil is not changed by rewinding it. In considering a special problem the time-constant of the circuit as a whole must be considered.

The time-constant of a circuit may be changed by placing the coils of an electromagnet in parallel instead of in series. Consider the case of a 150 ohm Morse relay connected at the end of an overhead line 200 miles long. The inductance of a single copper wire 0.104″ in diameter, suspended 20 ft. above the ground is about 2.5 milhenrys per mile, and the resistance about 5.1 ohms per mile. The resistance of the Morse relay is about 150 ohms, and it has a working inductance of about 4 henrys. The time-constant, i.e. $\frac{L}{R}$, for

the whole circuit is 0.00375 seconds.
the current in the line is considered co
stant, placing the two windings of t
relay in parallel has the resultant effect
a relay whose resistance and inductan
are one-fourth of the series values. Pu
ting the coils of the relay in paral
makes the circuit resistance 1087 ohn
the inductance 1.5 henrys, and the tin
constant becomes 0.00138 seconds. T
time-constant of the circuit with t
parallel arrangement of coils is about or
third of that with the series arrangemen

Curves showing the rate of rise of cu
rent in the above two circuits are shov
in Fig. 31, where the abscissae are te
thousandths of a second, and the ordi
ates per cent. of steady value, or $\frac{E}{R}$ valu
of current. The decrease in time-co
stant due to parallel arrangement
marked.

The magnetizing power, or amper
turns, of the parallel arrangement is on
half of that of the series arrangement, i.e

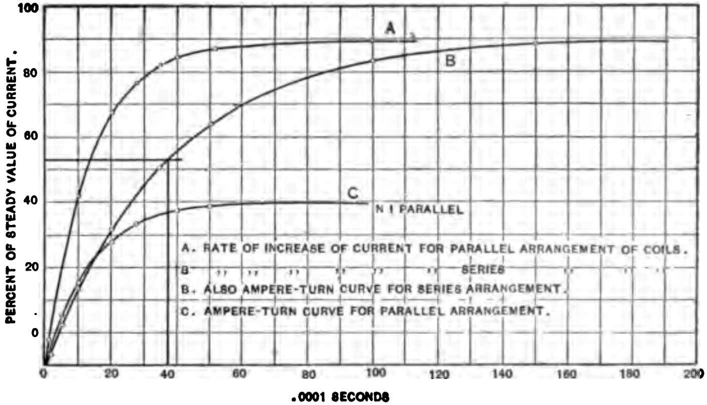

100
80
60
40
20
0
PERCENT OF STEADY VALUE OF CURRENT.
0
20
40
60
80
100
120
140
160
180
200
.0001 SECONDS
A
B
C
N I PARALLEL
A. RATE OF INCREASE OF CURRENT FOR PARALLEL ARRANGEMENT OF COILS.
B ,, ,, ,, ,, ,, ,, SERIES ,, ,,
B. ALSO AMPERE-TURN CURVE FOR SERIES ARRANGEMENT.
C. AMPERE-TURN CURVE FOR PARALLEL ARRANGEMENT.

Fig. 31.

in a constant current system. The magnetizing force being proportional to the current, curve I also gives the rate of increase of magnetizing force in the series-circuit, while curve III gives the rate of increase of magnetizing force for the parallel arrangement of coils. It is obvious that for very brief currents the magnetizing force is the greater for the parallel arrangement of coils.

In the consideration of quick-working electromagnets the resistance and inductance of the entire circuit must be considered in order to determine the best arrangement of terminal apparatus. The electro-static capacity of the line should be considered in very rapid telegraph work, but it makes the complete discussion of the problem very complicated.

CHAPTER V.

ALTERNATE CURRENT ELECTRO-MAGNETS.

By an alternating current is meant one which is periodically changing its direction of flow. From the consideration of the simplest forms of generator it may be shown that the E.M.F. varies harmonically; and it will be considered that the current varies according to a simple sine law as shown in Fig. 32.

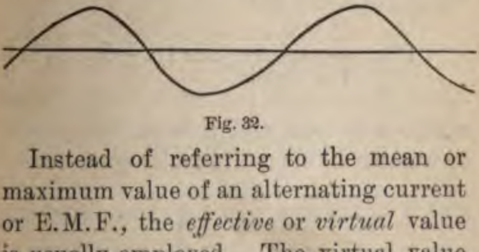


Fig. 32.

Instead of referring to the mean or maximum value of an alternating current or E.M.F., the *effective* or *virtual* value is usually employed. The virtual value of an alternating current is the value of an unvarying or direct current which

would produce the same heating effe
and is equal to the square root of
mean square of the instantaneous valu

Virtual value $=\frac{\text{max. value}}{\sqrt{2}}=0.707$ m
value. (

Max. value $= \sqrt{2}$ virtual value $= 1.4$
virtual value. (

When a simple harmonic E.M.
E sin pt, is applied to a circuit of resi
ance, R, and inductance, L, the relati
between E.M.F. and current is

$$I = \frac{E}{\sqrt{R^2+p^2L^2}} \sin (pt-\theta), \quad \text{(}$$

where $p = 2\pi n$, and n is the frequen
or number of complete cycles per seco
and $\theta = \text{arc tan.} \frac{Lp}{R}$, i.e., the angle
which the current lags behind the E.M.
in an inductive circuit. The quant
$(R^2+p^2L^2)^{\frac{1}{2}}$ is termed the impedance

the circuit. The quantity pL is called the reactance. Hence,

$$\overline{\text{Impedance}}^2 = \overline{\text{Resistance}}^2 + \overline{\text{Reactance}}^2. \tag{92}$$

In alternating current work it is necessary to know the inductance of the circuit, and this may be obtained by direct measurement, or, in the case of a closed magnetic circuit by the formula

$$L = \frac{4\pi N^2 A\mu}{10^9 l} \text{ henrys,} \tag{93}$$

where A is the cross-sectional area of the core in sq. cms., and l is the mean perimeter of the core in cms.

Hysteresis Loss.—It has been stated on page 42 that when the magnetic state is passing through a cycle of changes, energy is lost, due to hysteresis. This lost energy manifests itself in the form of heat. For alternate current work this loss of energy may be large, and undue heating of the core may result. The energy lost in hysteresis is given by the relation

Energy lost (watts) =

$$\frac{\text{volume in cu. cms.}}{10^7} f \eta B^{1.6}_{\text{max.}} \quad (94)$$

The following table gives the value of the hysteresis coefficient, η, for several grades of iron.

Grade of Iron.	Coefficient, η.
Very soft iron wire,	0.0020
Very thin soft sheet iron,	0.0024
Sheet iron,	0.0045
Soft annealed cast steel,	0.0080
Cast steel,	0.0120
Cast iron,	0.0162

The purer the iron the smaller the value of η.

Eddy Currents.—When a conducting body is exposed to an alternating magnetic field, electric currents are set up in the mass of the metal, due to the cutting of the lines of force. Such currents are known as *eddy* or *Foucault* currents. Eddy currents are a purely electrical phenomena, while hysteresis loss is a magnetic phenomena. Eddy currents produce a loss of energy and are dependent upon the shape of the metal and its degree of subdivision.

Power lost in eddy currents =

$$\frac{\text{Vol. in cu. cms.}}{10^7} f^2 E B^2 \qquad (95)$$

where E is the coefficient of eddy currents, and depends upon the material and shape of the parts of the magnetic circuit.

If the magnetic core is made up of laminated or sheet iron

$$\text{Power lost (watts)} = 1.645\, d^2 f^2 B^2 \times 10^{-11} \qquad (96)^1$$

per unit volume, where d is the thickness of the iron sheet in cms.

If the magnetic core is made up of iron wire,

$$\text{Power lost (watts)} = 0.617\, d_1^2 f^2 B^2 \times 10^{-11} \qquad (97)^1$$

per unit volume, where d_1 is the diameter of the wire in cms.

---

(1) Steinmetz. "Alternating Current Phenomena." 3d ed. pp. 132, 135.

The energy loss by eddy currents is decreased by increasing the degree of subdivision of the core.

For straight (or bar) electromagnets fine iron wire may be used for the core, while in horse-shoe magnets the core may be built up of iron stampings. If stampings are used the eddy currents may be further decreased by covering the sheets with shellac, or by interposing layers of insulating material, such as paper, mica, etc., and thus decreasing the electrical conductivity of the core. The oxide on the surface of the iron is usually relied upon for insulating purposes.

If the current flowing through the coil of an electromagnet varies periodically the resultant magnetic flux also varies periodically. The armature is then acted upon by a varying force which passes successively from zero to a maximum, and then back to zero. For one complete cycle of current or magnetic flux the armature has two maximums of attraction. For a current of low frequency, the armature wiil vibrate with a frequency double that of the current. As the current frequency increases the vibrations of the armature will be less manifest, and it will chatter against its stop, and finally, for higher frequencies the armature will be attracted without any chattering. The point at which the vibration and chattering cease depends largely upon the inertia of the armature.

The polarized type of electromagnet can be made to respond to a very small alternating current when the armature is placed in a biased position.

When current flows in two parallel conductors in the same direction there is an attraction between the two conductors, and a repulsion if the currents are flowing in opposite directions.

Consider two conductors conveying alternating currents which are in phase with one another, as indicated by Fig. 33.

There is a varying attraction between the conductors, which has maximum values at *b* and *d*. When the current frequency is high the wires do not vibrate but are urged towards one another.

Consider two conductors conveying alternating currents which are of opposite phase, i.e., 180° apart, as indicated by

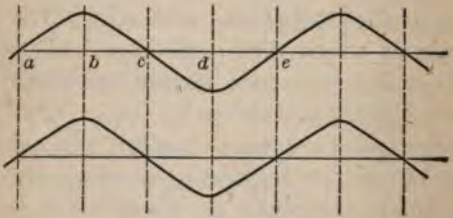


Fig. 33.

Fig. 34. Here there is a varying repulsion between the conductors which has maximum values at *b* and *d*. When the frequency is high the wires do not vibrate, but are urged away from one another.

Consider the intermediate case where the currents in the two conductors are in quadrature with each other, i.e., 90° apart in phase, as indicated by Fig. 35.

At *a*, *b*, *c*, *d* and *e* there are no forces

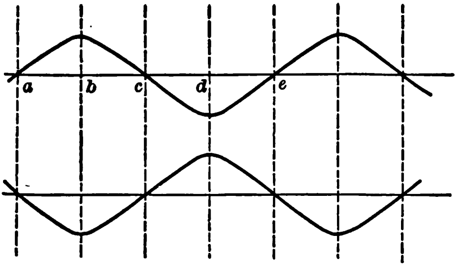


Fig. 34.

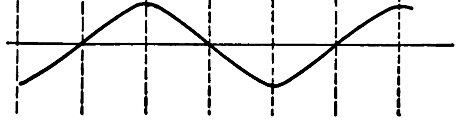


Fig. 35.

acting on the conductors, as on
has a zero value. From *a* to *b*
repulsion, from *b* to *c*, attractio
to *d* repulsion, and from *d* to *e* a
At low frequencies the conducto
with double the frequency of the
but at high current frequencies
no tendency to vibration.

If the current in the condu
out of step, and the difference is
or greater than, 90°, the attra
repulsions preponderate, and t
resultant motion; it being one
tion if the phase difference is
90°, and one of repulsion if t
difference is greater than 90°.

Consider a disc of copper whi
in front of the pole of an alterna
rent electromagnet. The magn
which cuts the disc is alternatin
two equal and opposite values.
nating E.M.F. is generated in
and hence there is an alternatin
flowing around the disc, and con
there is a force acting between

and the disc. Consider the upper half of Fig. 36.

Let the chain dotted curve, A B C D E, represent the variation of the magnetic

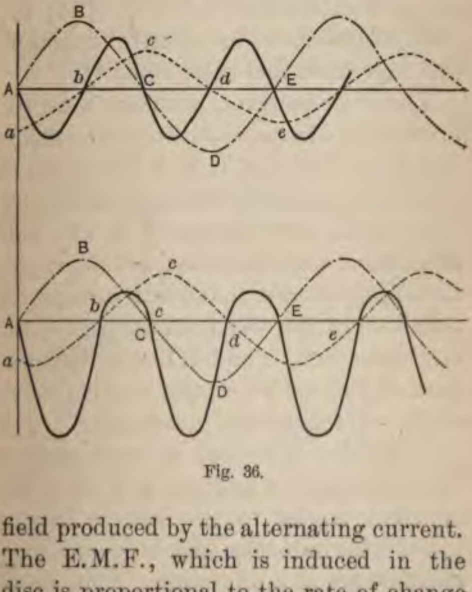


Fig. 36.

field produced by the alternating current. The E.M.F., which is induced in the disc is proportional to the rate of change of the magnetic flux, and is represented by the dotted curve *a b c d e*. If the dis was devoid of inductance the current i it could also be represented by the curv *a b c d e*. As the curves A B C D E an *a b c d e* are in quadrature there would b no resultant force acting on the disc; an the full line shows the relative attraction and repulsions and their equality.

The disc, however, possesses a certai amount of inductance, and the current lag behind the induced E.M.F., as shown b the dotted line in the lower part of Fig. 3 The disc is now subjected to alternat attractions and repulsions, but the repul sions preponderate and there is a resultan repulsion of the disc from the core of th electromagnet. The full line in the lowe part of Fig. 36 shows the relative valu of the attractions and repulsions.

If the disc is pivoted so as to rotate i will rotate into a position with its plan at right angles to the core. In thi position the induction and hence the edd currents are at a minimum. This prop erty of the repulsion of discs or masses of metal may be made use of in electro-magnets where repulsion of the armature is desired.

The disc should be made of copper, so that its resistance will be low, and the eddy currents as large as possible

APPENDIX.

I.—TABLES GIVING RELATIONS BETWEEN U. S. AND METRIC SYSTEMS.

1 Meter = 39.37 Inches.

No.	LONG MEASURE. 64th of an Inch to Millimeters.	Millimeters to 64to of an Inch.	Inches to Centimeters.	Centimeters to Inches.
1	0.397	2.520	2.54	0.394
2	0.794	5.039	5.08	0.787
3	1.191	7.559	7.62	1.181
4	1.587	10.079	10.16	1.575
5	1.984	12.598	12.70	1.968
6	2.381	15.118	15.24	2.362
7	2.778	17.638	17.78	2.756
8	3.175	20.157	20.32	3.150
9	3.572	22.677	22.86	3.543

No.	SQUARE MEASURE.		CUBIC MEASURE,	
	Sq. Inches to Square Centimeters	Square Centimeters to Square Inches.	Cubic Inches to Cubic Centimeters.	Cubic Centimeters to Cubic Inches.
1	6.452	0.155	16.393	0.061
2	12.903	0.310	32.787	0.122
3	19.355	0.465	49.180	0.183
4	25.806	0.620	65.574	0.244
5	32.258	0.775	81.947	0.305
6	38.710	0.930	98.361	0.366
7	45.161	1.085	114.75	0.427
8	51.613	1.240	131.15	0.488
9	58.065	1.395	147.54	0.549

II.—PROPERTIES OF COPPER WIRE.

BROWN AND SHARPE GAUGE.

Gauge Number.	Diameter in Mils.	Area in Circular Mils. C.M.=d^2	Weight. Pounds per Foot. 20° C. = 68° F.	Length. Feet per Ohm. 20° C. = 68° F.	Resist'nce Ohms per Foot. 20° C. = 68° F.
1	289.3	83,690	0.2533	8,083	0.0001237
2	257.6	66,370	0.2009	6,410	0.0001560
3	229.4	52,630	0.1593	5,084	0.0001967
4	204.3	41,740	0.1264	4,031	0.0002480
5	181.9	33,100	0.1002	3,197	0.0003128
6	162.0	26,250	0.07946	2,535	0.0003944
7	144.3	20,820	0.06302	2,011	0.0004973
8	128.5	16,510	0.04998	1,595	0.0006271
9	114.4	13,090	0.03963	1,265	0.0007908
10	101.9	10,380	0.03143	1,003	0.0009972
11	90.74	8,234	0.02493	795.3	0.001257
12	80.81	6,530	0.01977	630.7	0.001586
13	71.96	5,178	0.01568	500.1	0.001999
14	64.08	4,107	0.01243	396.6	0.002521
15	57.07	3,257	0.009858	314.5	0.003179
16	50.82	2,583	0.007818	249.4	0.004009
17	45.26	2,048	0.006200	197.8	0.005055
18	40.30	1,624	0.004917	156.9	0.006374
19	35.89	1,288	0.003899	124.4	0.008038
20	31.96	1,022	0.003092	98.66	0.01014
21	28.46	810.1	0.002452	78.24	0.01278
22	25.35	642.4	0.001945	62.05	0.01612
23	22.57	509.5	0.001542	49.21	0.02032
24	20.10	404.0	0.001223	39.02	0.02563
25	17.90	320.4	0.0009699	30.95	0.03231
26	15.94	254.1	0.0007692	24.54	0.04075
27	14.20	201.5	0.0006100	19.46	0.05138
28	12.64	159.8	0.0004837	15.43	0.06479
29	11.26	126.7	0.0003836	12.24	0.08170
30	10.03	100.5	0.0003042	9.707	0.1030
31	8.928	79.70	0.0002413	7.698	0.1299
32	7.950	63.21	0.0001913	6.105	0.1638
33	7.080	50.13	0.0001517	4.841	0.2066
34	6.305	39.75	0.0001203	3.839	0.2605
35	5.615	31.52	0.00009543	3.045	0.3284
36	5.000	25.00	0.00007568	2.414	0.4142

Compiled from "Copper Wire Tables" of Am. Inst. of Engrs.

III.—PROPERTIES OF COPPER WIRE.

B. W. GAUGE.

Gauge Number.	Diameter in Mils.	Area in Circular Mils. C. M. =d²	Weight. Pounds per Foot. 20° C. = 68° F,	Length. Feet per Ohm. 20° C. = 68° F.	Resist'nce Ohms per Foot. 20° C. = 68° F.
1	300.0	90000.	0.2724	8,692.	0.0001150
2	284.0	80660.	0.2441	7,790.	0.0001284
3	259.0	67080.	0.2031	6,479.	0.0001543
4	238.0	56640.	0.1715	5,471.	0.0001828
5	220.0	48400.	0.1465	4,675.	0.0002139
6	203.0	41210.	0.1247	3,980.	0.0002513
7	180.0	32400.	0.09808	3,129.	0.0003196
8	165.0	27230.	0.08241	2,629.	0.0003803
9	148.0	21900.	0.06630	2,116.	0.0004727
10	134.0	17960.	0.05435	1,734.	0.0005766
11	120.0	14400.	0.04359	1,391.	0.0007190
12	109.0	11880.	0.03596	1,147.	0.0008715
13	95.0	9025.	0.02732	871.7	0.001147
14	83.0	6889.	0.02085	665.4	0.001503
15	72.0	5184.	0.01569	500.7	0.001997
16	65.0	4225.	0.01279	408.1	0.002451
17	58.0	3364.	0.01018	324.9	0.003078
18	49.0	2401.	0.007268	231.9	0.004312
19	42.0	1764.	0.005340	170.4	0.005870
20	35.0	1225.	0.003708	118.3	0.008452
21	32.0	1024.	0.003100	98.90	0.01011
22	28.0	784.	0.002373	75.72	0.01321
23	25.0	625.	0.001892	60.36	0.01657
24	22.0	484.	0.001465	46.75	0.02139
25	20.0	400.	0.001211	38.63	0.02588
26	18.0	324.	0.0009808	31.29	0.03196
27	16.0	256.	0.0007749	24.73	0.04045
28	14.0	196.	0.0005933	18.93	0.05283
29	13.0	169.	0.0005116	16.32	0.06127
30	12.0	144.	0.0004359	13.91	0.07190
31	10.0	100.	0.0003027	9.658	0.1035
32	9.0	81.	0.0002452	7.823	0.1278
33	8.0	64.	0.0001937	6.181	0.1618
34	7.0	49.	0.0001483	4.733	0.2113
35	5.0	25.	0.0007568	2.414	0.4142
36	4.0	16.	0.0004843	1.545	0.6471

IV.—Temperature Coefficients.

Temperature Degrees.		Temperature Coefficient of Resistance.	
Centigrade.	Fahrenheit.	0°C. = 32° F. as Standard.	20° C. = 68° F. as Standard.
0	32	1.0000	......
5	41	1.0195	......
10	50	1.0393	......
15	59	1.0594	......
20	68	1.0797	1.0000
25	77	1.1003	1.0191
30	86	1.1210	1.0383
35	95	1.1422	1.0579
40	104	1 1633	1.0774
45	113	1.1848	1.0973
50	122	1.2063	1.1172
55	131	1.2282	1.1375
60	140	1.2500	1.1577
65	149	1.2716	1.1777
70	158	1.2933	1.1978
80	176	1.3368	1.2324
90	194	1.3800	1.2781
100	212	1.4223	1.3173

V.—WEIGHT OF COPPER IN 100 LBS. OF INSULATED WIRE.

Size of Wire, B S G'ge	SILK				COTTON	
	SINGLE			DOUBLE	SINGLE	DOUBLE
	1½ mil increase	2 mil increase	3 mil increase	4 mil increase	4 mil increase	8 mil increase
20	99.	98.5	97.8	97.	96.2	92.2
21	98.8	98.3	97.5	96.5	95.5	90.8
22	98.6	98.	97.2	96.2	95.	89.8
23	98.4	97.8	96.8	95.8	94.3	88.6
24	98.2	97.7	96.3	95.2	93.7	87.
25	98.	97.2	95.8	94.6	92.8	85.5
26	97.8	97.	95.3	93.8	91.8	83.8
27	97.5	96.7	94.8	93.	90.8	81.7
28	97.2	96.2	94.2	92.2	89.7	79.5
29	96.8	95.7	93.4	91.2	88.5	77.
30	96.3	95.2	92.6	90.6	87.	74.5
31	95.8	94.6	91.7	88.6	85.5	71.3
32	95.4	93.8	90.5	87.3	83.7	68.3
33	94.8	93.	89.25	85.7	81.8	64.7
34	94.2	92.2	87.8	83.7	79.4	61.
35	93.4	91.2	86.7	82.2	76.8	57.
36	92.6	89.25	84.7	79.3	74.3	52.8
37	91.6	88.4	82.6	76.7	71.2	48.7
38	90.5	87.2	80.4	73.8	68.	44.4
39	89.2	85.7	77.2	70.8	64.6	40.2
40	88.1	83.8	75.5	67.7	60.8	35.8

COMPUTED FROM THE FOLLOWING DATA:—

Size of Wire. B.&S.	Diam. of Wire (bare)	Diam. insul. with Silk	Diam. insul. with Cotton	Weight of Product	Weight of Silk	Weight of Cotton
29	.01126	.01326		104.5	4.5	
29	.01126		.01526	112.95		12.95

This Table is taken, by permission, from "The Electro-Magnet," by Wolcott, Kennelly, and Varley.

CATALOGUE

OF THE

SCIENTIFIC PUBLICATIONS

OF

D. VAN NOSTRAND COMPANY,

23 MURRAY STREET AND 27 WARREN STREET, N. Y.

A. B. C. CODE. (See Clausen-Thue.)

ABBOTT (A. V.). The Electrical Transmission of Energy. A Manual for the Design of Electrical Circuits. Second edition, revised. Fully illustrated. 8vo, cloth.......................................$4 50

ABBOT (Gen'l HENRY L.). The Defence of the Seacoast of the United States. Lectures delivered before the U. S. Naval War College. 8vo, red cloth. 2 00

ADAMS (J. W.). Sewers and Drains for Populous Districts. Embracing Rules and Formulas for the dimensions and construction of works of Sanitary Engineers. Fifth edition. 8vo, cloth. 2 50

A1. CODE. (See Clausen-Thue.)

AIKMAN (C. M., Prof.). Manures and the Principles of Manuring. 8vo, cloth.................. .... 2 50

ALEXANDER (J. H.). Universal Dictionary of Weights and Measures, Ancient and Modern, reduced to the Standards of the United States of America. New edition, enlarged. 8vo, cloth.............. ... 3 50

ALEXANDER (S. A.). Broke Down: What Should I Do? A Ready Reference and Key to Locomotive Engineers and Firemen, Round House Machinists, Conductors, Train Hands and Inspectors. With 5 folding plates. 12mo, cloth........... .... 1 50

ALLEN (C. F.). Tables for Earthwork Computation. 8vo, cloth 1 50

ANDERSON (J. W.). The Prospector's Hand-book; A Guide for the Prospector and Traveller in search of Metal-bearing or other Valuable Minerals. Seventh edition, thoroughly revised and much enlarged. 8vo, cloth.. 1 50

ANDERSON (WILLIAM). On the Conversion of Heat into Work. A Practical Hand-book on Heat-Engines. Third edition. Illustrated. 12mo, cloth. 2 25

ANDES (LOUIS). Vegetable Fats and Oils; their Practical Preparation, Purification and Employment for various purposes. Their Properties, Adulteration and Examination. A Hand-book for Oil Manufacturers and Refiners, Candle, Soap and Lubricating Oil Manufacturers and the Oil and Fat Industry in general. Translated from the German. With 94 illustrations. 8vo, cloth.............................. 4 00

—— Animal Fats and Oils. Their Practical Production, Purification and Uses for a great variety of purposes, their Properties, Falsification and Examination. A Hand-book for Manufacturers of Oil and Fat Products, Soap and Candle Makers, Agriculturists, Tanners, etc. Translated by Charles Salter. With 62 illustrations. 8vo, cloth.... ....net 4 00

ARNOLD (Dr. R.). Ammonia and Ammonium Compounds. A Practical Manual for Manufacturers, Chemists, Gas Engineers and Drysalters. Second edition. 12mo, cloth.............................. 2 00

ARNOLD (E.). Armature Windings of Direct Current Dynamos. Extension and Application of a General Winding Rule. Translated from the original German by Francis B. DeGress, M. E. With numerous illustrations.................................(In Press.)

ATKINSON (PHILIP). The Elements of Electric Lighting, including Electric Generation, Measurement, Storage, and Distribution. Ninth edition. Fully revised and new matter added. Illustrated. 12mo, cloth.. .... 1 50

—— The Elements of Dynamic Electricity and Magnetism. Third edition. 120 illustrations. 12mo, cloth 2 00

ATKINSON (PHILIP). Power Transmitted by Electricity and its Application by the Electric Motor, including Electric Railway Construction. New edition, thoroughly revised, and much new matter added. Illustrated. 12mo, cloth.... .... 2 00

—— Elements of Static Electricity, with full description of the Holtz and Topler Machines, and their mode of operating. Illustrated. 12mo, cloth....... 1 50

AUCHINCLOSS (W. S.). Link and Valve Motions Simplified. Illustrated with 29 woodcuts and 20 lithographic plates, together with a Travel Scale, and numerous useful tables, Thirteenth edition, revised. 8vo, cloth.................................. 2 00

AXON (W. E. A.). The Mechanic's Friend. A Collection of Receipts and Practical Suggestions. 12mo, cloth 1 50

BACON (F. W.). A Treatise on the Richards, Steam-Engine Indicator, with directions for its use. By Charles T. Porter. Revised, with notes and large additions as developed by American practice; with an appendix containing useful formulæ and rules for engineers. Illustrated. Fourth edition. 12mo, cloth 1 00

BADT (F. B.). New Dynamo Tender's Hand book. With 140 illustrations. 18mo, cloth............... 1 00

—— Bell Hangers' Hand-book. With 97 illustrations. Second edition. 18mo, cloth............. .... 1 00

—— Incandescent Wiring Hand-book. With 35 illustrations and five tables. Fifth edition. 18mo, cloth. 1 00

—— Electric Transmission Hand-book. With 22 illustrations and 27 tables. 18mo, cloth................ 1 00

BALE (M. P.). Pumps and Pumping. A Hand-book for Pump Users. 12mo, cloth..... .... 1 00

BARBA (J.). The Use of Steel for Constructive Purposes. Method of Working, Applying, and Testing Plates and Bars With a Preface by A. L. Holley, C. E. 12mo, cloth......................... ..... 1 50

BARKER (ARTHUR H.). Graphic Methods of Engine Design. Including a Graphical Treatment of the Balancing of Engines. 12mo, cloth.... ..... 1 50

BARNARD (F. A. P.). Report on Machinery and Processes of the Industrial Arts and Apparatus of the Exact Sciences at the Paris Universal Exposition, 1867. 152 illustrations and 8 folding plates. 8vo, cloth.. 5 0

BARNARD (JOHN H.). The Naval Militiaman's Guide. Full leather, pocket form.................... 1 2

BARWISE (SIDNEY, M. D., London). The Purification of Sewage. Being a brief account of the Scientific Principles of Sewage Purification and their Practical Application. 12mo, cloth. Illustrated. 2 0

BAUMEISTER (R.). The Cleaning and Sewage of Cities. Adapted from the German with permission of the author. By J. M. Goodell, C. E. Second edition, revised and corrected, together with an additional appendix. 8vo, cloth. Illustrated....... 2 0

BEAUMONT (ROBERT). Color in Woven Design. With 32 Colored Plates and numerous original illustrations. Large 12mo.............................. 7 5

BEAUMONT, W. and DUGALD CLERK. Autocars and Horseless Carriages............. (In Press.)

BECKWITH (ARTHUR). Pottery. Observations on the Materials and Manufacture of Terra-Cotta, Stoneware. Fire-Brick, Porcelain. Earthenware, Brick, Majolica, and Encaustic Tiles. 8vo, paper. Second edition.................................... 6

BERNTHSEN (A.). A Text-Book of Organic Chemistry. Translated by George M'Gowan, Ph. D. Third English edition. Revised and extended by author and translator. Illustrated. 12mo, cloth............ 2 5

BERTIN (L. E.). Marine Boilers: Their Construction and Working, dealing more especially with Tubulous Boilers. Translated by Leslie S. Robertson, Upward of 250 illustrations. Preface by Sir William White. 8vo, cloth. Illustrated........................ 7 5

BIGGS (C. H. W.). First Principles of Electricity and Magnetism. Being an attempt to provide an Elementary Book for those intending to enter the profession of Electrical Engineering. Second edition. 12mo, cloth. Illustrated.............................. 2

BLAKE (W. P.). Report upon the Precious Metals. Being Statistical Notices of the principal Gold and Silver producing regions of the world, represented at the Paris Universal Exposition. 8vo, cloth........ 2 00

—— Ceramic Art. A Report on Pottery, Porcelain, Tiles, Terra-Cotta, and Brick. 8vo, cloth............ 2 00

BLAKESLEY (T. H.). Alternating Currents of Electricity. For the use of Students and Engineers. Third edition, enlarged. 12mo, cloth................ 1 50

BLOUNT (BERTRAM). Electro-Metallurgy .... (In Press.)

BLYTH (A. WYNTER, M. R. C. S., F. C. S.). Foods: their Composition and Analysis. A Manual for the use of Analytical Chemists, with an Introductory Essay on the History of Adulterations, with numerous tables and illustrations. Fourth edition, revised and enlarged. 8vo, cloth.................... 7 50

—— Poisons: their Effects and Detection. A Manual for the use of Analytical Chemists and Experts, with an Introductory Essay on the growth of Modern Toxicology. Third edition, revised and enlarged. 8vo, cloth.................................... 7 50

BODMER (G. R.). Hydraulic Motors; Turbines and Pressure Engines, for the use of Engineers, Manufacturers and Students. Second edition, revised and enlarged. With 204 illustrations. 12mo, cloth...... 5 00

BOILEAU (J. T.). A New and Complete Set of Traverse Tables. Showing the Difference of Latitude and Departure of every minute of the Quadrant and to five places of decimals. 8vo, cloth. 5 00

BOTTONE (S. R.). Electrical Instrument Making for Amateurs. A Practical Hand-book. With 48 illustrations. Fifth edition, revised. 12mo, cloth....... 50

—— Electric Bells, and all about them. A Practical Book for Practical Men. With more than 100 illustrations. 12mo, cloth. Fourth edition, revised and enlarged.. 50

——The Dynamo: How Made and How Used. A Book for Amateurs. Eighth edition. 12mo, cloth... 1 00

BOTTONE (S. R.). Electro Motors: How Made and How Used. A Hand-book for Amateurs and Practical Men. Second edition. 12mo, cloth................. 50

BONNEY (G. E.). The Electro-Platers' Hand-book. A Manual for Amateurs and Young Students on Electro-Metallurgy. 60 illustrations, 12mo, cloth.. 1 20

BOW (R. H.). A Treatise on Bracing. With its application to Bridges and other Structures of Wood or Iron. 156 illustrations. 8vo, cloth.................. 1 50

BOWSER (Prof. E. A.). An Elementary Treatise on Analytic Geometry. Embracing Plane Geometry, and an Introduction to Geometry of three Dimensions. 12mo, cloth. Nineteenth edition.............. 1 75

—— An Elementary Treatise on the Differential and Integral Calculus. With numerous examples. 12mo, cloth. Sixteenth edition.... .... 2 25

—— An Elementary Treatise on Analytic Mechanics. With numerous examples. 12mo, cloth. Twelfth edition.. 3 00

—— An Elementary Treatise on Hydro-Mechanics. With numerous examples. 12mo, cloth Fifth edition.. 2 50

—— A Treatise on Roofs and Bridges. With Numerous Exercises. Especially adapted for school use. 12mo, cloth. Illustrated........ ....net 2 25

—— Academic Algebra. Third edition. 12mo, cloth.. 1 25

—— College Algebra. Fourth edition. 12mo, cloth.. 1 75

—— Elements of Plane and Solid Geometry. 12mo, cloth. Second edition............................ 1 40

BOWIE (AUG. J., Jun., M. E.). A Practical Treatise on Hydraulic Mining in California. With Description of the Use and Construction of Ditches, Flumes, Wrought-iron Pipes and Dams; Flow of Water on Heavy Grades, and its Applicability, under High Pressure, to Mining. Fifth edition. Small quarto, cloth. Illustrated.................................. 5 00

BURGH (N. P.). Modern Marine Engineering, applied to Paddle and Screw Propulsion. Consisting of 36 colored plates, 259 practical woodcut illustrations, and 403 pages of descriptive matter. The whole being an exposition of the present practice of James Watt & Co., J. & G. Rennie, R. Napier & Sons, and other celebrated firms. Thick quarto, half morocco. 10 00

BURT (W. A.). Key to the Solar Compass, and Surveyor's Companion. Comprising all the rules necessary for use in the field; also description of the Linear Surveys and Public Land System of the United States. Notes on the Barometer, Suggestions for an Oufit for a Survey of Four Months, etc. Fifth edition. Pocket-book form, tuck 2 50

CALDWELL, (G. C.), and A. A. BRENEMAN. Manual of Introductory Chemical Practice. For the use of Students in Colleges and Normal and High Schools. Fourth edition, revised and corrected. 8vo, cloth Illustrated.......... .... 1 50

CAMPIN (FRANCIS). On the Construction of Iron Roofs. A Theoretical and Practical Treatise, with wood cuts and Plates of Roofs recently executed. 8vo, cloth... 2 00

CARTER (E. T.). Motive Power and Gearing for Electrical Machinery. A Treatise on the Theory and Practice of the Mechanical Equipment of Power Stations for Electric supply and for Electic Traction. 8vo, cloth. Illustrated........... .... 5 00

CHAMBER'S MATHEMATICAL TABLES, consisting of logarithms of Numbers 1 to 108,000, Trigonometrical, Nautical, and other tables. New edition. 8vo, cloth........................ .... 1 75

CHAUVENET (Prof. W.). New Method of Correcting Lunar Distances, and Improved Method of Finding the Error and Rate of a Chronometer, by Equal Altitudes. 8vo, cloth 2 00

CHRISTIE (W. WALLACE). Chimney Design and Theory. A Book for Engineers and Architects, with numerous half-tone illustrations and plates of famous chimneys. 12mo, cloth.................... .... 3 00

CHURCH (JOHN A.). Notes of a Metallurgical Journey in Europe. 8vo, cloth.......................... 2 00

CLARK D. (KINNEAR, C. E.). A Manual of Rules, Tables and Data for Mechanical Engineers. Based

on the most recent investigations. Illustrated with numerous diagrams. 1,012 pages. 8vo, cloth. Sixth edition 5 00
Half morocco 7 50

CLARK D. (KINNEAR, C. E.). Fuel; its Combustion and Economy, consisting of abridgements of Treatise on the Combustion of Coal. By C. W. Williams; and the Economy of Fuel, by T. S. Prideaux. With extensive additions in recent practice in the Combustion and Economy of Fuel, Coal, Coke, Wood, Peat, Petroleum, etc. Fourth edition. 12mo, cloth.. 1 50

—— The Mechanical Engineer's Pocket-book of Tables, Formulæ, Rules and Data. A Handy Book of Reference for Daily Use in Engineering Practice. 16mo, morocco. Second edition.......................... 3 00

——Tramways, their Construction and Working, embracing a comprehensive history of the system, with accounts of the various modes of traction, a description of the varieties of rolling stock, and ample details of Cost and Working Expenses. Second edition. Re-written and greatly enlarged, with upwards of 400 illustrations. Thick 8vo, cloth. 9 00

—— The Steam Engine. A Treatise on Steam Engines and Boilers; comprising the Principles and Practice of the Combustion of Fuel, the Economical Generation of Steam, the Construction of Steam Boilers, and the Principles, Construction and Performance of Steam Engines, Stationary, Portable, Locomotive and Marine, exemplified in Engines and Boilers of recent date. 1,300 figures in the text, and a series of folding plates drawn to scale. 2 vols. 8vo, cloth 15 00

CLARK (JACOB M.). A new System of Laying Out Railway Turn-outs instantly, by inspection from Tables. 12mo, leatherette.......................... 1 00

CLAUSEN-THUE (W.). The A. B. C. Universal Commercial Electric Telegraphic Code; especially adapted for the use of Financiers, Merchants, Ship owners, Brokers, Agent, etc. Fourth edition. 8vo, cloth. 5 00

—— The A1 Universal Commercial Electric Telegraphic Code. Over 1,240 pp., and nearly 90,000 variations. 8vo, cloth.. 7 50

CLEEMANN (THOS. M.). The Railroad Engineer's Practice. Being a Short but Complete Description of the Duties of the Young Engineer in the Preliminary and Location Surveys and in Construction. Fourth edition. Revised and enlarged. Illustrated. 12mo, cloth.................................... 1 50

CLERK (DUGALD). Auto-cars or Horseless Vehicles. About 300 pp., 60 illustrations......... ....(In Press.)

CLEVENGER (S. R.). A Treatise on the Method of Government Surveying as prescribed by the U. S. Congress and Commissioner of the General Land Office, with complete Mathematical, Astronomical and Practical Instructions for the use of the United States Surveyors in the field. 16mo, morocco... ... 2 50

COFFIN (Prof. J. H. C.). Navigation and Nautical Astronomy. Prepared for the use of the U. S. Naval Academy. New Edition. Revised by Commander Charles Belknap. 52 woodcut illustrations. 12mo, cloth ....net. 3 50

COLE (R. S., M. A.). A Treatise on Photographic Optics. Being an account of the Principles of Optics, so far as they apply to Photography. 12mo, cloth, 103 illustrations and folding plates............ 2 50

COLLINS (JAS. E.). The private Book of Useful Alloys, and Memoranda for Goldsmiths, Jewelers, etc. 18mo, cloth 50

CORNWALL (Prof. H. B.). Manual of Blow-pipe Analysis, Qualitative and Quantitative. With a Complete System of Descriptive Mineralogy. 8vo, cloth. With many illustrations...................... 2 50

CRAIG (B. F.). Weights and Measures. An Account of the Decimal System, with Tables of Conversion for Commercial and Scientific Uses. Square 32mo, limp cloth.. 50

CROCKER (F. B.). Electric Lighting. A Practical Exposition of the Art, for use of Engineers, Students, and others interested in the Installation or Operation of Electrical Plants. Second edition. Revised. 8vo, cloth. Vol. 1. The Generating Plant 3 00
Vol. 2...... .... (In Press.)

CROCKER, (F. B.), and S. S. WHEELER. The Practical Management of Dynamos and Motors. Fourth edition (eighth thousand). Revised and enlarged. With a special chapter by H. A. Foster. 12mo, cloth. Illustrated.......................... 1 00

CUMMING (LINNÆUS, M. A.). Electricity treated Experimentally. For the use of Schools and Students New edition. 12mo, cloth.......................... 1 50

DAVIES (E. H.). Machinery for Metalliferous Mines. A Practical Treatise for Mining Engineers, Metallurgists and Manufacturers. With upwards of 300 illustrations. 8vo, cloth.......................... 5 00

DAVIS (JOHN W., C. E.). Formulæ for the Calculation of Railroad Excavation and Embankment, and for finding Average Haul. Second edition. Octavo, half roan.......................... 1 50

DAY (CHARLES). The Indicator and its Diagrams. With Chapters on Engine and Boiler Testing; Including a Table of Piston Constants compiled by W. H. Fowler. 12mo, cloth. 125 illustrations....... 2 00

DERR (W. L.). Block Signal Operation. A Practical Manual. Oblong, cloth.......................... 1 50

DIXON (D. B.). The Machinist's and Steam Engineer's Practical Calculator. A Compilation of Useful Rules and Problems arithmetically solved, together with General Information applicable to Shop-Tools, Mill Gearing, Pulleys and Shafts, Steam-Boilers and Engines. Embracing valuable Tables and Instruction in Screw-cutting, Valve and Link Motion, etc. 16mo, full morocco, pocket form.................... 1 25

DODD (GEO.). Dictionary of Manufactures, Mining, Machinery, and the Industrial Arts. 12mo, cloth ... 1 50

DORR (B. F). The Surveyor's Guide and Pocket Table Book. 18mo, morocco flaps. Third edition... 2 00

DRAPER (C. H.). An Elementary Text Book of Light, Heat and Sound, with Numerous Examples. Fourth edition. 12mo, cloth. Illustrated.. .... 1 00

——Heat and the Principles of Thermo-Dyramics. With many illustrations and numerical examples. 12mo, cloth.......................... 1 50

DUBOIS (A. J.). The New Method of Graphic Statics. With 60 illustrations. 8vo, cloth.......... 1 50

EDDY (Prof. H. T.). Researches in Graphical Statics. Embracing New Constructions in Graphical Statics, a New General Method in Graphical Statics, and the Theory of Internal Stress in Graphical Statics. 8vo, cloth.......................... .. 1 50

—— Maximum Stresses under Concentrated Loads. Treated graphically. Illustrated. 8vo, cloth........ 1 50

EISSLER (M.). The Metallurgy of Gold; a Practical Treatise on the Metallurgical Treatment of Gold-Bearing Ores, including the Processes of Concentration and Chlorination, and the Assaying, Melting and Refining of Gold. Fourth Edition, revised and greatly enlarged. 187 illustrations. 12mo, cloth 5 00

——The Metallurgy of Silver; a Practical Treatise on the Amalgamation, Roasting and Lixivation of Silver Ores, including the Assaying, Melting and Refining of Silver Bullion. 124 illustrations. Second edition, enlarged, 12mo, cloth.................... .... 4 00

——The Metallurgy of Argentiferous Lead; a Practical Treatise on the Smelting of Silver Lead Ores and the Refining of Lead Bullion. Including Reports on Various Smelting Establishments and Descriptions of Modern Smelting Furnaces and Plants in Europe and America. With 183 illustrations. 8vo, cloth 5 00

—— Cyanide Process for the Extraction of Gold and its Practical Application on the Witwatersrand Gold Fields in South Africa. Second edition. Enlarged. 8vo, cloth. Illustrations and folding plates......... 3 00

—— A Hand-book on Modern Explosives, being a Practical Treatise on the Manufacture and use of Dynamite, Gun Cotton, Nitro-Glycerine and other Explosive Compounds, including the manufacture of Collodion-Cotton, with chapters on explosives in practical application. Second edition, enlarged with 150 illustrations. 12mo, cloth.......... .... 5 00

ELIOT (C. W.), and STORER (F. H.). A compendious Manual of Qualitative Chemical Analysis. Revised with the co-operation of the authors, by Prof. William R. Nichols. Illustrated. Nineteenth edition, newly revised by Prof. W. B. Lindsay, 12mo, cloth.. .... 1 25

ELLIOT (Maj. GEO. H.). European Light-House Systems. Being a Report of a Tour of Inspection made in 1873. 51 engravings and 21 woodcuts. 8vo, cloth 5 00

ELLISON, (LEWIS M.). Practical Application of the Indicator. With reference to the adjustment of Valve Gear on all styles of Engines. Second edition, revised. 8vo. cloth, 100 illustrations................ 2 00

EVERETT (J. D.). Elementary Text-book of Physics. Illustrated. Seventh edition. 12mo, cloth 1 50

EWING (Prof. A. J.). The Magnetic Induction in Iron and other metals. 159 illustrations. 8vo, cloth 4 00

FANNING (J. T.). A Practical Treatise on Hydraulic and Water-Supply Engineering. Relating to the Hydrology, Hydro-dynamics, and Practical Construction of Water-Works in North America. 180 illustrations. 8vo, cloth. Fourteenth edition, revised, enlarged, and new tables and illustrations added. 650 pages.................................... 5 00

FISH (J. C. L.). Lettering of Working Drawings. Thirteen plates, with descriptive text. Oblong, 9x12½, boards.. 1 00

FISKE (Lieut. BRADLEY A., U. S. N.). Electricity in Theory and Practices or, The Elements of Electrical Engineering. Eighth edition. 8vo, cloth 2 50

FISHER (H. K. C. and DARBY, W. C.). Students' Guide to Submarine Cable Testing. 8vo, cloth...... 2 50

FISHER (W. C.). The Potentiometer and its Adjuncts. 8vo, cloth.................................... 2 25

FLEISCHMANN (W.). The Book of the Dairy. A Manual of the Science and Practice of Dairy Work. Translated from the German, by C. M. Aikman and R. Patrick Wright. 8vo, cloth........................... 4 00

FLEMING (Prof. J. A.). The Alternate Current Transformer in Theory and Practice. Vol. 1—The Induction of Electric Currents; 611 pages. New edition. Illustrated. 8vo, cloth........................ 5 00
Vol. 2. The Utilization of Induced Currents. Illustrated. 8vo, cloth 5 00

—— Electric Lamps and Electric Lighting. Being a course of four lectures delivered at the Royal Institution, April-May, 1894. 8vo, cloth, fully illustrated 3 00

FLEMING (Prof. J. A.). Electrical Laboratory Notes and Forms, Elementary and advanced. 4to, cloth, illustrated.. 5 00

FOLEY (NELSON), and THOS. PRAY, Jr. The Mechanical Engineers' Reference Book for Machine and Boiler Construction, in 2 parts. Part 1—General Engineering Data. Part 2—Boiler Construction. With fifty-one plates and numerous illustrations, specially drawn for this work. Folio, half mor. ...25 00

FORNEY (MATTHIAS N.). Catechism of the Locomotive. Second edition, revised and enlarged. Forty-sixth thousand. 8vo, cloth.................... 3 50

FOSTER (Gen. J. G., U. S. A.). Submarine Blasting in Boston Harbor, Massachusetts. Removal of Tower and Corwin Rocks. Illustrated with 7 plates 4to, cloth.. 3 50

FOSTER (H. A.). Electrical Engineers' Pocket Book. 1000 pages with the collaboration of Eminent Specialists.....................................(In press)

FOSTER (JAMES). Treatise on the Evaporation on Saccharine, Chemical and other Liquids by the Multiple System in Vacuum and Open Air. Second edition. Diagrams and large plates. 8vo, cloth.... 7 50

FOWLER. Mechanical Engineers' Pocket Book for 1900.. 1 00

FOX (WM.), and C. W. THOMAS, M. E. A Practical Course in Mechanical Drawing. 12mo, cloth with plates 1 25

FRANCIS (JAS. B., C. E.). Lowell Hydraulic Experiments. Being a selection from experiments on Hydraulic Motors, on the Flow of Water over Weirs, in open Canals of uniform rectangular section, and through submerged Orifices and diverging Tubes. Made at Lowell, Mass. Fourth edition, revised and enlarged, with many new experiments, and illustrated with 23 copper-plate engravings. 4to, cloth...15 00

FROST (GEO. H.). Engineer's Field Book. By C. S. Cross. To which are added seven chapters on Railroad Location and Construction. Fourth edition. 12mo, cloth 1 00

HASKINS (C. H.). The Galvanometer and its Uses. A Manual for Electricians and Students. Fourth edition. 12mo, cloth.......................... 1 50

HAWKE (WILLIAM H.). The Premier Cipher Telegraphic Code Containing 100,000 Words and Phrases. The most complete and most useful general code yet published. 4to, cloth........................ 5 00

—— 100,000 Words; Supplement to the Premier Code. All the words are selected from the official vocabulary. Oblong quarto, cloth.............................. 4 20

HAWKINS (C. C.) and WALLIS (F.). The Dynamo; its Theory, Design and Manufacture. 190 illustrations, 12mo, cloth.................................. 3 00

HAY (ALFRED). Principles of Alternate-Current Working. 12mo, cloth, illustrated.................... 2 00

HEAP (Major D. P., U. S. A.). Electrical Appliances of the Present Day. Report of the Paris Electrical Exposition of 1881. 250 illustrations. 8vo, cloth..... 2 00

HEAVISIDE (OLIVER). Electromagnetic Theory. 8vo, cloth, two volumes each.......................... 5 00

HENRICI (OLAUS). Skeleton Structures. Applied to the Building of Steel and Iron Bridges. Illustrated 1 50

HERRMANN (GUSTAV). The Graphical Statics of Mechanism. A Guide for the Use of Machinists, Architects, and Engineers; and also a Text-book for Technical Schools. Translated and annotated by A. P. Smith, M. E. 12mo, cloth, 7 folding plates. Third Edition.. 2 00

HERMANN (FELIX). Painting on Glass and Porcelain and Enamel Painting. On the Basis of Personal Practical Experience of the Condition of the Art up to date Translated by Charles Salter. Second greatly enlarged edition. 8vo, cloth, Illustrations, net... 3 50

HEWSON (WM.). Principles and Practice of Embanking Lands from River Floods, as applied to the Levees of the Mississippi. 8vo, cloth................ 2 00

HILL (JOHN W.). The Purification of Public Water Supplies. Illustrated with valuable Tables, Diagrams and Cuts. 8vo, cloth, 304 pages.............. 3 00

—— The Interpretation of Water Analyses. (In Press)

HOBBS (W. R. P.). The Arithmetic of Electrical Measurements with numerous examples. Fully Worked, 12mo, cloth.................................. .50

HOFF (WM. B., Com. U. S. Navy.). The Avoidance of Collisions at Sea. 18mo, morocco .... .75

HOLLEY (ALEXANDER L.). Railway Practice. American and European Railway practice in the Economical Generation of Steam. 77 lithographed plates. Folio, cloth 12 00

HOLMES (A. BROMLEY). The Electric Light Popularly Explained. Fifth Edition. Illustrated. 12mo, paper .... .40

HOPKINS (NEVIL M.). Model Engines and small Boats. New Methods of Engine and Boiler Making with a chapter on Elementary Ship Design and Construction. 12mo, cloth......... .... 1 25

HOSPITALIER (E.). Polyphased Alternating Currents. Illustrated. 8vo, cloth. 1 40

HOWARD (C. R.). Earthwork Mensuration on the Basis of the Prismoidal Formulae. Containing Simple and Labor-saving Methods of obtaining Prismoidal Contents directly from End Areas. Illustrated by Examples and accompained by Plain Rules for Practical Uses. Illustrated. 8vo, cloth... ..... 1 50

HUMBER (WILLIAM, C. E.). A Handy Book for the Calculation of Strains in Girders and Similar Structures, and their Strength; Consisting of Formulae and Corresponding Diagrams, with numerous details for practical application, etc. Fourth Edition. 12mo, cloth....... .... 2 50

HURST (GEORGE H.). Colour; A Hand-book of the Theory of Colour. Containing ten coloured plates and 72 diagrams. 8vo, cloth. Illustrated. Price.... 2 50

—— Lubricating Oils, Fats and Greases. Their Origin, Preparation, Properties, Uses and Analysis. 313 pages, with 65 illustrations. 8vo, cloth............. 3 00

—— Soaps; A Practical Manual of the Manufacture of Domestic, Toilet and other Soaps. Illustrated with 66 Engravings. 8vo, cloth.......................

HUTCHINSON (W. B.). Patents and How to Make Money out of Them. Member of New York Bar. 12mo, cloth. New York, 1899 .... 1 25

HUTTON (W. S.). Steam Boiler Construction. A Practical Hand-book for Engineers, Boiler Makers and Steam Users. Containing a large collection of rules and data relating to recent practice in the design, construction, and working of all kinds of stationary, locomotive and marine steam boilers. With upwards of 500 illustrations. Third edition. Carefully revised and much enlarged. 8vo, cloth... 6 00

—— Practica Engineer's Hand-book, Comprising a treatise on Modern Engines and Boilers, Marine, Locomotive and Stationary. Fourth edition. Carefully revised with additions. With upwards of 570 illustrations. 8vo, cloth.............................. 7 00

—— The Works' Manager's Hand-book of Modern Rules, Tables, and Data for Civil and Mechanical Engineers. Millwrights and Boiler Makers, etc., etc. With upwards of 150 illustrations. Fifth edition. Carefully revised, with additions. 8vo, cloth....... 6 00

INNES (CHARLES H.). Problems in Machine Design. For the Use of Students, Draughtsmen and others. 12mo, cloth.. 1 50

—— Centrifugal Pumps, Turbines and Water Motors. Including the Theory and Practice of Hydraulics. 12mo, cloth.. 1 50

ISHERWOOD (B. F.). Engineering Precedents for Steam Machinery. Arranged in the most practical and useful manner for Engineers. With illustrations. 2 vols. in 1. 8vo, cloth.................. .... 2 50

JAMESON (CHARLES D.). Portland Cement. Its Manufacture and Use. 8vo, cloth.......................... 1 50

JAMIESON (ANDREW C. E.). A Text-Book on Steam and Steam Engines. Specially arranged for the use of Science and Art, City and Guilds of London Institute, and other Engineering Students. Tenth edition. Illustrated. 12mo, cloth.................... 3 00

—— Elementary Manual on Steam and the Steam Engine. Specially arranged for the use of First-Year Science and Art, City and Guilds of London Institute, and other Elementary Engineering Students. Third edition. 12mo, cloth 1 40

JANNETTAZ (EDWARD). A Guide to the Determination of Rocks: being an Introduction to Lithology. Translated from the French by G. W. Plympton, Professor of Physical Science at Brooklyn Polytechnic Institute. 12mo, cloth.............. 1 50

JOHNSTON, Prof. J. F. W., and CAMERON, Sir CHAS. Elements of Agricultural Chemistry and Geology. Seventeenth edition. 12mo, cloth......... 2 60

JOYNSON (F. H.). The Metals used in Construction. Iron, Steel, Bessemer Metal, etc. Illustrated. 12mo, cloth.. 75

—— Designing and Construction of Machine Gearing. Illustrated. 8vo, cloth.. .... 2 00

KANSAS CITY BRIDGE (THE.) With an Account of the Regimen of the Missouri River and a Description of the Methods used for Founding in that River. By O. Chanute, Chief Engineer, and George Morrison, Assistant Engineer. Illustrated with 5 lithographic views and 12 plates of plans. 4to, cloth... 6 00

KAPP (GISBERT C. E.). Electric Transmission of Energy and its Transformation, Subdivision, and Distribution. A Practical Hand-book. Fourth edition, revised. 12mo, cloth............. .... 3 50

—— Dynamos, Alternators and Transformers. 138 Illustrations. 12mo, cloth........... .... 4 00

KEMPE (H. R.). The Electrical Engineer's Pocket-Book of Modern Rules, Formulæ, Tables and Data. Illustrated. 32mo, mor. gilt.......................... 1 75

KENNELLY (A. E.). Theoretical Elements of Electro-Dynamic Machinery. 8vo, cloth...... .... 1 50

KILGOUR, M. H., SWAN, H., and BIGGS, C. H. W. Electrical Distribution; its Theory and Practice. 174 Illustrations. 12mo, cloth........................ 4 00

KING (W. H.). Lessons and Practical Notes on Steam. The Steam Engine, Propellers, etc., for Young Marine Engineers, Students, and others. Revised by Chief Engineer J. W. King, United States Navy. Nineteenth edition, enlarged. 8vo, cloth.... 2 00

KINGDON (J. A.). Applied Magnetism. An Introduction to the Design of Electromagnetic Apparatus. 8vo, cloth..................... .... 3 00

KIRKALDY (WM. G.). Illustrations of David Kirkaldy's System of Mechanical Testing, as Originated and Carried On by him during a Quarter of a Century. Comprising a Large Selection of Tabulated Results, showing the Strength and other Properties of Materials used in Construction, with explanatory Text and Historical Sketch. Numerous engravings and 25 lithographed plates. 4to, cloth.................... 20 00

KIRKWOOD (JAS. P.). Report on the Filtration of River Waters for the supply of Cities, as practised in Europe, made to the Board of Water Commissioners of the City of St. Louis. Illustrated by 30 double-plate engravings. 4to, cloth........................ 7 50

LARRABEE (C. S.). Cipher and Secret Letter and Telegraphic Code, with Hog's Improvements. The most perfect Secret Code ever invented or discovered. Impossible to read without the key. 18mo, cloth 60

LAZELLE (H. M.). One Law in Nature. A New Corpuscular Theory comprehending Unity of Force, Identity of Matter, and its Multiple Atom Constitution, etc. 12mo, cloth.............................. 1 50

LEASK (A. RITCHIE). Breakdowns at Sea and How to Repair Them. With eighty-nine Illustrations. 8vo, cloth. Second edition.................... 2 00

—— Triple and Quadruple Expansion Engines and Boilers and their Management. With fifty-nine illustrations. Third edition, revised. 12mo, cloth.. 2 00

—— Refrigerating Machinery: Its Principles and Management. With sixty-four illustrations. 12mo, cloth 2 00

LECKY (S. T. S.). "Wrinkles" in Practical Navigation. With 130 illustrations. 8vo, cloth. Ninth edition, revised.................................... 8 40

LEVY (C. L.). Electric Light Primer. A Simple and Comprehensive Digest of all of the most important facts connected with the running of the dynamo, and electric lights, with precautions for safety. For the use of persons whose duty it is to look after the plant. 8vo, paper.................................. 50

LIVACHE (ACH., Ingenieur Civil Des Mines). The Manufacture of Varnishes, Oil Crushing, Refining and Boiling and Kindred Industries. Translated from the French and greatly extended, by John Geddes McIntosh. 8vo, cloth. Illustrated.......net 5 00

LOCKE (ALFRED G., and CHARLES G.) A Practical Treatise on the Manufacture of Sulphuric Acid. With 77 Constructive Plates drawn to Scale Measurements, and other Illustrations. Royal 8vo, cloth.10 00

LOCKERT (LOUIS). Petroleum Motor-Cars. 12mo, cloth 1 50

LOCKWOOD (THOS. D.). Electricity, Magnetism, and Electro-Telegraphy. A Practical Guide for Students, Operators, and Inspectors. 8vo, cloth. Third edition.. 2 50

—— Electrical Measurement and the Galvanometer; its Construction and Uses. Second edition. 32 illustrations. 12mo, cloth.................................. 1 50

LODGE (OLIVER J.). Elementary Mechanics, including Hydrostatics and Pneumatics. Revised edition. 12mo, cloth.................................. 1 50

LORING (A. E.). A Hand-book of the Electro-Magnetic Telegraph. Paper boards...................... 50
Cloth.. 75
Morocco.. 1 00

LUCE (Com. S. B.). Text-Book of Seamanship. The Equipping and Handling of Vessels under Sail or Steam. For the use of the U. S. Naval Academy. Revised and enlarged edition, by Lt. Wm. S. Benson. 8vo, cloth......................................10 00

LUNGE (GEO.). A Theoretical and Practical Treatise on the Manufacture of Sulphuric Acid and Alkali with the Collateral Branches. Vol. I. Sulphuric Acid, Second edition, revised and enlarged. 342 Illustrations. 8vo, cloth............................15 00
Vol. II. Second edition, revised and enlarged. 8vo, cloth..16 80
Vol III. 8vo, cloth. New edition, 1896..................15 00

LUNGE. (GEO.), and HURTER, F. The Alkali Maker's Pocket-Book. Tables and Analytical Methods for Manufacturers of Sulphuric Acid, Nitric Acid, Soda, Potash and Ammonia. Second edition. 12mo, cloth 3 00

LUQUER (LEA McILVAINE, Ph. D.). Minerals in Rock Sections. The Practical Method of Identifying Minerals in Rock Sections with the microscope, Especially arranged for Students in Technical and Scientific Schools. 8vo. cloth. Illustrated..net 1 50

MACCORD (Prof. C. W.). A Practical Treatise on the Slide-Valve by Eccentrics, examining by methods the action of the Eccentric upon the Slide-Valve, and explaining the practical processes of laying out the movements, adapting the Valve for its various duties in the Steam Engine. Second edition. Illustrated. 4to, cloth.................................. 2 50

MAGUIRE (Capt. EDWARD. U. S. A.). The Attack and Defence of Coast Fortifications. With Maps and Numerous Illustrations. 8vo, cloth...... 2 50

MAGUIRE (WM. R.). Domestic Sanitary Drainage and Plumbing Lectures on Practical Sanitation. 332 illustrations. 8vo..... . ... 4 00

MARKS (EDWARD C. R.). Mechanical Engineering Materials: their Properties and Treatment in Construction. 12mo, cloth. Illustrated................. 60

—— Notes on the Construction of Cranes and Lifting Machinery. 12mo, cloth... .... 1 00

MARKS (G. C.). Hydraulic Machinery Employed in the Concentration and Transmission of Power. 12mo, cloth............... .... 1 25

MAVER (WM.). American Telegraphy: Systems, Apparatus, Operation. 450 illustrations. 8vo, cloth. 3 50

MAYER (Prof. A. M.). Lecture Notes on Physics. 8vo, cloth.. 2 00

McCULLOCH (Prof. R. S.). Elementary Treatise on the Mechanical Theory of Heat, and its application to Air and Steam Engines. 8vo, cloth.......... 3 50

McNEILL (BEDFORD). McNeill's Code. Arranged to meet the requirements of Mining, Metallurgical and Civil Engineers, Directors of Mining, Smelting and other Companies, Bankers, Stock and Share Brokers, Solicitors, Accountants, Financiers, and General Merchants. Safety and Secrecy. 8vo, cloth 6 00

MERRILL (Col. WM. E., U. S. A.). Iron Truss Bridges for Railroads. The method of calculating strains in Trusses, with a careful comparison of the most prominent Trusses, in reference to economy in combination, etc. Illustrated. 4to, cloth. Fourth Edition 5 00

METAL TURNING. By a Foreman Pattern Maker. Illustrated with 81 engravings. 12mo, cloth........ 1 50

MINIFIE (WM.). Mechanical Drawing. A Text-book of Geometrical Drawing for the use of Mechanics and Schools, in which the Definitions and Rules of Geometry are familiarly explained; the Practical Problems are arranged from the most simple to the more complex, and in their description technicalities are avoided as much as possible. With illustrations for Drawing Plans, Sections, and Elevations of Railways and Machinery; an Introduction to Isometrical Drawing, and an Essay on Linear Perspective and Shadows. Illustrated with over 200 diagrams engraved on steel. Ninth thousand. With an appendix on the Theory and Application of Colors. 8vo, cloth 4 00

—— Geometrical Drawing. Abridged from the Octavo edition, for the use of schools. Illustrated with 48 steel plates. Ninth edition. 12mo, cloth.... .... 2 00

MODERN METEOROLOGY. A Series of Six Lectures, delivered under the auspices of the Meteorological Society in 1870. Illustrated. 12mo, cloth . 1 50

MOREING (C. A.), and NEAL (THOMAS). Telegraphic Mining Code Alphabetically arranged. Second edition. 8vo, cloth.............................. .... 8 40

MORRIS (E.). Easy Rules for the Measurement of Earthworks by means of the Prismoidal Formula. 8vo, cloth. Illustrated...... .... 1 50

MOSES (ALFRED J.), and PARSONS, C. L. Elements of Mineralogy, Crystallography and Blowpipe Analysis from a practical standpoint. Second thousand. 8vo, cloth. 366 illustrations...... ...net 2 00

MOSES (ALFRED J.). The Characters of Crystals. An Introduction to Physical Crystallography, containing 321 Illustrations and Diagrams. 8vo, 211 pp...................................... ....net 2 00

MOELLER (F. C. G.). Krupp's Steel Works. With 88 illustrations. By Felix Schmidt and Montan. Authorized Translation from the German. 4to, cloth.............................. .....(In Press.)

MULLIN (JOSEPH P., M. E.). Modern Moulding and Pattern-Making. A Practical Treatise upon Pattern Shop and Foundry Work; embracing the Moulding of Pulleys, Spur Gears, Worm Gears, Balance-Wheels, Stationary Engine and Locomotive Cylinders, Globe Valves, Tool Work, Mining Machinery, Screw Propellers, Pattern-Shop Machinery, and the latest improvements in English and American Cupolas; together with a large collection of original and carefully selected Rules and Tables for everyday use in the Drawing Office, Pattern-Shop and Foundry. 12mo, cloth. Illustrated................. 2 50

MUNRO (JOHN C. E.), and JAMIESON ANDREW. C. E. A Pocket-book of Electrical Rules and Tables for the use of Electricians and Engineers. Thirteenth edition, revised and enlarged. With numerous diagrams. Pocket size. Leather.. 2 50

MURPHY (J. G., M. E.). Practical Mining. A Field Manual for Mining Engineers. With Hints for Investors in Mining Properties. 16mo, morocco tucks.................. .... 1 00

NAQUET (A.). Legal Chemistry. A Guide to the Detection of Poisons, Falsification of Writings, Adulteration of Alimentary and Pharmaceutical Substances, Analysis of Ashes, and examination of Hair, Coins, Arms, and Stains, as applied to Chemical Jurisprudence. Translated from the French, by J. P. Battershall, Ph D., with a preface by C. F. Chandler, Ph. D., M. D., LL. D. 12mo, cloth........ 2 00

NASMITH (JOSEPH). The Student's Cotton Spinning. Third edition, revised and enlarged. 8vo, cloth. 622 pages. 250 Illustrations................. 3 00

NEWALL (JOHN W.). Plain Practical Directions for Drawing, Sizing and Cutting Bevel-Gears, showing how the Teeth may be cut in a Plain Milling Machine or Gear Cutter so as to give them a correct shape from end to end; and showing how to get out all particulars for the Workshop without making any Drawings. Including a Full Set of Tables of Reference. Folding plates. 8vo, cloth.. .... 1 50

NEWCOMB (EDWARD W.). Stepping Stones to Photography. 12mo, cloth. Illustrated. N. Y., 1899. (In Press.)

NEWLANDS (JAMES). The Carpenters' and Joiners' Assistant: being a Comprehensive Treatise on the Selection, Preparation and Strength of Materials, and the Mechanical Principles of Framing. Illustrated. Folio, half morocco....................15 00

NIPHER (FRANCIS E., A. M.). Theory of Magnetic Measurements, with an appendix on the Method of Least Squares. 12mo, cloth 1 00

NOAD (HENRY M.). The Students' Text-Book of Electricity. A new edition, carefully revised. With an Introduction and additional chapters by W. H. Preece. With 471 illustrations. 12mo, cloth........ 4 00

NUGENT (E.). Treatise on Optics; or, Light and Sight theoretically and practically treated, with the application to Fine Art and Industrial Pursuits. With 103 illustrations. 12mo, cloth, ... 1 50

O'CONNOR (HENRY). The Gas Engineer's Pocket-Book. Comprising Tables, Notes and Memoranda; relating to the Manufacture, Distribution and Use of Coal Gas and the Construction of Gas Works. 12mo, full leather, gilt edges........................ 3 50

OUDIN (M. A.). Standard Polyphase Apparatus and Systems. Fully illustrated........ .... 3 00

PAGE (DAVID). The Earth's Crust, A Handy Outline of Geology. 16mo, cloth........................ 75

PALAZ (A., ScD.). A Treatise on Industrial Photometry, with special application to Electric Lighting. Authorized translation from the French, by George W. Patterson, Jr. Second edition, revised. 8vo, cloth. Illustrated................ .... 4 00

PARSHALL (H. F.), and HOBART H. M. Armature Windings of Electric Machines. With 140 full page plates, 65 tables, and 165 pages of descriptive letter-press. 4to, cloth....................... . 7 50

PARSHALL (H. F.), and EVAN PARRY. Electrical Equipment of Tramways......(In Press.)

PEIRCE (B.). System of Analytic Mechanics. 4to, cloth 10 00

—— Linear Associative Algebra. New edition, with addenda and notes, by C. L. Pierce. 4to, cloth 4 00

PERRINE (F. A. C., A. M., D. Sc.). Conductors for Electrical Distribution; their Manufacture and Materials, the Calculation of Circuits, Pole Line Construction, Underground Working and other Uses. (In Press.)

PERRY (JOHN). Applied Mechanics. A Treatise for the use of students who have time to work experimental, numerical and graphical exercises illustrating the subject. 8vo, cloth. 650 pages.,net 2 50

PHILLIPS (JOSHUA). Engineering Chemistry. A Practical Treatise for the use of Analytical Chemists, Engineers, Iron Masters, Iron Founders, students and others. Comprising methods of Analysis and Valuation of the principal materials used in Engineering works, with numerous Analyses, Examples and Suggestions. 314 illustrations. Second edition, revised and enlarged. 8vo, cloth.......... . 4 00

PICKWORTH (CHAS. N.). The Indicator Handbook. A Practical Manual for Engineers. Part I. The Indicator: Its Construction and Application. 81 illustrations. 12mo, cloth........................... 1 50

—— The Slide Rule. A Practical Manual of Instruction for all Users of the Modern Type of Slide Rule, exhibiting the Application of the Instrument to the Everyday Work of the Engineer,—Civil, Mechanical and Electrical. 12mo, flexible cloth. Fifth edition. 80

PLANE TABLE (THE). Its Uses in Topographical Surveying. From the Papers of the United States Coast Survey. Illustrated. 8vo, cloth............... 2 00

PLANTE (GASTON). The Storage of Electrical Energy, and Researches in the Effects created by Currents, combining Quantity with High Tension. Translated from the French by Paul B. Elwell. 89 illustrations. 8vo............... .... 4 00

PLATTNER. Manual of Qualitative and Quantitative Analysis with the Blow-Pipe. From the last German edition, revised and enlarged, by Prof. Th. Richter, of the Royal Saxon Mining Academy. Translated by Prof. H. B. Cornwall, assisted by John H. Caswell. Illustrated with 87 wood-cuts and one lithographic plate. Seventh edition, revised. 560 pages. 8vo, cloth......... .... 5 00

PLYMPTON (Prof. GEO. W.). The Blow Pipe. A Guide to its use in the Determination of Salts and Minerals. Compiled from various sources. 12mo, cloth 1 50

—— The Aneroid Barometer: its Construction and Use. Compiled from several sources. Fourth edition. 16mo, boards. Illustrated.......... 50
Morocco.......... 1 00

POCKET LOGARITHMS, to Four Places of Decimals, including Logarithms of Numbers, and Logarithmic Sines and Tangents to Single Minutes. To which is added a Table of Natural Sines, Tangents, and Co-Tangents. 16mo, boards.......... 50

POPE (F. L.). Modern Practice of the Electric Telegraph. A Technical Hand-book for Electricians, Managers and Operators. Fifteenth edition, rewritten and enlarged, and fully illustrated. 8vo, cloth. 1 50

POPPLEWELL (W. C.). Elementary Treatise on Heat and Heat Engines. Specially adapted for engineers and students of engineering. 12mo, cloth. Illustrated.......... 3 00

POWLES (H. H.). Steam Boilers..........(In Press.)

PRAY (Jr., THOMAS). Twenty Years with the Indicator; being a Practical Text-Book for the Engineer or the Student, with no complex Formulæ. Illustrated. 8vo, cloth.......... 2 50

—— Steam Tables and Engine Constant. Compiled from Regnault, Rankine and Dixon directly, making use of the exact records. 8vo, cloth.......... 2 00

PRACTICAL IRON FOUNDING. By the Author of "Pattern Making," &c., &c. Illustrated with over one hundred engravings. 12mo, cloth.......... 1 50

PREECE (W. H.). Electric Lamps ....(In Press.)

PREECE (W. H.), and STUBBS, A. T. Manual of Telephony. Illustrations and plates. 12mo, cloth. 4 50

PREMIER CODE. (See Hawk, Wm. H.)

PRESCOTT (Prof. A. B.). Organic Analysis. A Manual of the Descriptive and Analytical Chemistry of certain Carbon Compounds in Common Use: a Guide in the Qualitative and Quantitative Analysis of Organic Materials in Commercial and Pharmaceutical Assays, in the estimation of Impurities under Authorized Standards, and in Forensic Examinations for Poisons, with Directions for Elementary Organic Analysis. Fourth edition. 8vo, cloth..... 5 00

PRESCOTT (Prof. A. B.). Outlines of Proximate Organic Analysis, for the Identification, Separation, and Quantitative Determination of the more commonly occurring Organic Compounds. Fourth edition. 12mo, cloth... .... 1 75

—— First Book in Qualitative Chemistry. Eighth edition. 12mo, cloth 1 50

—— and Otis Coe Johnson. Qualitative Chemical Analysis. A Guide in the Practical Study of Chemistry and in the work of Analysis. Fourth fully revised edition. With Descriptive Chemistry extended throughout.................... .... 3 50

PRITCHARD (O. G.). The Manufacture of Electric Light Carbons. Illustrated. 8vo, paper 60

PULLEN (W. W. F.). Application of Graphic Methods to the Design of Structures. Specially prepared for the use of Engineers. 12mo, cloth. Illustrated. net 2 50

PULSIFER (W. H.). Notes for a History of Lead. 8vo, cloth, gilt tops........ .... 4 00

PYNCHON (Prof. T. R.). Introduction to Chemical Physics, designed for the use of Academies, Colleges, and High Schools. Illustrated with numerous engravings, and containing copious experiments with directions for preparing them. New edition, revised and enlarged, and illustrated by 269 illustrations on wood. 8vo, cloth.............................. 3 00

RADFORD (Lieut. CYRUS S.). Hand-book on Naval Gunnery. Prepared by Authority of the Navy Department. For the use of U. S. Navy, U. S. Marine Corps and U. S. Naval Reserves. Revised and enlarged, with the assistance of Stokely Morgan, Lieut. U. S. N. Third edition. 12mo, flexible leather. 2 00

RAFTER (GEO. W.), and M. N. BAKER. Sewage Disposal in the United States. Illustrations and folding plates. Second edition. 8vo, cloth........ 6 00

RAM (GILBERT S.). The Incandescent Lamp and its Manufacture. 8vo, cloth.. .... 3 00

RANDALL (J. E.). A Practical Treatise on the Incandescent Lamp. Illustrated. 16mo, cloth..... 50

RANDALL (P. M.). Quartz Operator's Hand-book. New edition, revised and enlarged, fully illustrated. 12mo, cloth.......... 2 00

RANKINE (W. J. MACQUORN.) Applied Mechanics. Comprising the Principles of Statics and Cinematics, and Theory of Structures, Mechanism, and Machines. With numerous diagrams. Fifteenth edition. Thoroughly revised by W. J. Millar. 8vo, cloth.......... 5 00

—— Civil Engineering. Comprising Engineering Surveys, Earthwork, Foundations, Masonry, Carpentry, Metal Work, Roads, Railways, Canals, Rivers, Water Works, Harbors, etc. With numerous tables and illustrations. Twentieth edition. Thoroughly revised by W. J. Millar. 8vo, cloth.......... 6 50

—— Machinery and Millwork. Comprising the Geometry, Motions, Work, Strength, Construction, and Objects of Machines, etc. Illustrated with nearly 300 wood cuts. Seventh edition. Thoroughly revised by W. J. Millar. 8vo, cloth.......... 5 00

—— The Steam Engine and other Prime Movers. With diagram of the Mechanical Properties of Steam-folding plates, numerous tables and illustrations. Thirteenth edition. Thoroughly revised by W. J. Millar. 8vo, cloth.......... 5 00

—— Useful Rules and Tables for Engineers and Others. With appendix, tables, tests, and formulæ for the use of Electrical Engineers. Comprising Submarine Electrical Engineering, Electric Lighting, and Transmission of Power. By Andrew Jamieson, C. E., F. R. S. E. Seventh edition. Thoroughly revised by W. J. Millar. Crown 8vo, cloth. 4 00

—— A Mechanical Text-Book. By Prof. Macquorn Rankine and E. F. Bamber, C. E. With numerous illustrations. Fourth edition. 8vo, cloth.......... 3 50

RAPHAEL (F. C.). Localisation of Faults in Electric Light Mains. 8vo, cloth.......... 2 00

RECKENZAUN (A.). Electric Traction on Railways and Tramways. 213 illustrations. 12mo, cloth..... 4 00

REED'S ENGINEERS' HAND-BOOK to the Local Marine Board Examinations for Certificates of Competency as First and Second Class Engineers. By W. H. Thorn. With the answers to the Elementary Questions. Illustrated by 297 diagrams and 36 large plates. Sixteenth edition, revised and enlarged. 8vo, cloth................................ 5 00

—— Key to the Sixteenth Edition of Reed's Engineer's Hand-book to the Board of Trade Examinations for First and Second Class Engineers and containing the working of all the questions given in the examination papers. By W. H. Thorn. 8vo, cloth.. 3 00

—— Useful Hints to Sea-going Engineers, and How to Repair and Avoid "Break Downs;" also Appendices Containing Boiler Explosions, Useful Formulæ, etc. With 36 diagrams and 4 plates. Second edition, revised and enlarged. 12mo, cloth.................. 1 40

—— Marine Boilers: A Treatise on the Causes and Prevention of their Priming, with Remarks on their General Management. Illustrated. 12mo, cloth... 2 00

REINHARDT (CHAS. W.). Lettering for Draftsmen, Engineers and Students. A Practical System of Free-hand Lettering for Working Drawings. Fourth thousand. Oblong, boards.................. 1 00

RICE (J. M.)., and JOHNSON, W. W. On a New Method of obtaining the Differential of Functions, with especial reference to the Newtonian Conception of Rates or Velocities. 12mo, paper.... 50

RINGWALT (J. L.). Development of Transportation Systems in the United States, Comprising a Comprehensive Description of the leading features of advancement from the colonial era to the present time. With illustrations. Quarto, half morocco.. 7 50

RIPPER (WILLIAM). A Course of Instruction in Machine Drawing and Design for Technical Schools and Engineer Students. With 52 plates and numerous explanatory engravings. Folio, cloth.......... 6 00

ROEBLING (J. A.). Long and Short Span Railway Bridges. Illustrated with large copperplate engravings of plans and views. Imperial folio, cloth...25 00

ROGERS (Prof. H. D.). The Geology of Pennsylvania. A Government Survey, with a General View of the Geology of the United States, essays on the Coal Formation and its Fossils, and a description of the Coal Fields of North America and Great Britain. Illustrated with plates and engravings in the text. 3 vols., 4to, cloth, with portfolio of maps. 15 00

ROSE (JOSHUA, M. E.). The Pattern-Makers' Assistant. Embracing Lathe Work, Branch Work, Core Work, Sweep Work, and Practical Gear Constructions, the Preparation and Use of Tools, together with a large collection of useful and valuable Tables. Eighteenth edition. Illustrated with 250 engravings. 8vo, cloth........................ 2 50

—— Key to Engines and Engine-running. A Practical Treatise upon the Management of Steam Engines and Boilers for the Use of Those who Desire to Pass an Examination to Take Charge of an Engine or Boiler. With numerous illustrations, and Instructions Upon Engineers' Calculations, Indicators, Diagrams, Engine Adjustments, and other Valuable Information necessary for Engineers and Firemen. 12mo, cloth.. 2 50

SABINE (ROBERT). History and Progress of the Electric Telegraph. With descriptions of some of the apparatus. Second edition, with additions. 12mo, cloth.. 1 25

SAELTZER (ALEX.). Treatise on Acoustics in connection with Ventilation. 12mo, cloth.............. 1 00

SALOMONS (Sir DAVID, M. A.). Electric Light Installations. A Practical Hand-book. Eighth edition, revised and enlarged, with numerous illustrations. Vol. I. The management of Accumulators. 12mo, cloth.............................. 1 50
Vol. II., Apparatus, 296 illustrations. 12mo, cloth. 2 25
Vol. III., Applications. 12mo, cloth............... 1 50

SANFORD (P. GERALD). Nitro-Explosives. A Practical Treatise concerning the Properties, Manufacture and Analysis of Nitrated Substances, including the Fulminates, Smokeless Powders and Celluloid. 8vo, cloth, 270 pages........................ 3 00

SAUNNIER (CLAUDIUS). Watchmaker's Handbook. A Workshop Companion for those engaged in Watchmaking and allied Mechanical Arts. Translated by J. Tripplin and E. Rigg. Second edition, revised with appendix. 12mo, cloth................ 3 50

SCHELLEN (Dr. H.). Magneto-Electric and Dynamo-Electric Machines: their Construction and Practical Application to Electric Lighting, and the Transmission of Power. Translated from the third German edition, by N. S. Keith and Percy Neymann, Ph. D. With very large additions and notes relating to American Machines, by N. S. Keith. Vol. I., with 353 illustrations. Second edition....................... 5 00

SCHUMANN (F.). A Manual of Heating and Ventilation in its Practical Application, for the use of Engineers and Architects. Embracing a series of Tables and Formulæ for dimensions of heating, flow and return pipes for steam and hot-water boilers, flues, etc. 12mo, illustrated, full roan. 1 50

SCRIBNER (J. M.). Engineers' and Mechanics' Companion. Comprising United States Weights and Measures. Mensuration of Superfices and Solids, Tables of Squares and Cubes, Square and Cube Roots, Circumference and Areas of Circles, the Mechanical Powers, Centres of Gravity, Gravitation of Bodies, Pendulums, Specific Gravity of Bodies, Strength, Weight, and Crush of Materials, Water-Wheels, Hydrostatics, Hydraulics, Statics, Centres of Percussion and Gyration, Friction Heat, Tables of the Weight of Metals, Scantling, etc., Steam and the Steam Engine. Twentieth edition revised. 16mo, full morocco..................... .... 1 50

SEATON (A. E.). A Manual of Marine Engineering. Comprising the Designing, Construction and Working of Marine Machinery. With numerous tables and illustrations reduced from Working Drawings. Fourteenth edition. Revised throughout, with an additional chapter on Water Tube Boilers. 8vo., cloth............ .... 6 00

—— **and ROUNTHWAITE (H. M.).** A Pocket-book of Marine Engineering Rules and Tables. For the use of Marine Engineers and Naval Architects, Designers, Draughtsmen, Superintendents, and all engaged in the design and construction of Marine Machinery, Naval and Mercantile. Fifth edition, revised and enlarged. Pocket size. Leather, with diagrams. Reprinting. 2

SEXTON (A. HUMBOLDT). Fuel and Refractory Materials. 8vo, cloth.................................... 2 00

SHIELDS (J. E.). Notes on Engineering Construction. Embracing Discussions of the Principles involved, and Descriptions of the Material employed in Tunnelling, Bridging, Canal and Road Building, etc. 12mo, cloth.. 1 50

SHOCK (WM. H.). Steam Boilers: Their Design, Construction and Management. 4to, half morocco.15 00

SHREVE (S. H.). A Treatise on the Strength of Bridges and Roofs. Comprising the determination of Algebraic formulas for strains in Horizontal, Inclined or Rafter, Triangular, Bowstring, Lenticular, and other Trusses, from fixed and moving loads, with practical applications and examples, for the use of Students and Engineers. 87 woodcut illus. Fourth edition. 8vo, cloth.............................. 3 50

SHUNK (W. F.). The Field Engineer. A Handy Book of practice in the Survey, Location, and Truckwork of Railroads, containing a large collection of Rules and Tables, original and selected, applicable to both the Standard and Narrow Gauge, and prepared with special reference to the wants of the young Engineer. Eleventh edition, revised and enlarged. 12mo, morocco, tucks..................... 2 50

SIMMS (F. W.). A Treatise on the Principles and Practice of Levelling. Showing its application to purposes of Railway Engineering, and the Construction of Roads, etc. Revised and corrected, with the addition of Mr. Laws' Practical Examples for setting out Railway Curves. Illustrated. 8vo, cloth.. 2 50

SIMMS (W. F.). Practical Tunnelling. Fourth edition, revised and greatly extended. With additional chapters illustrating recent practice by D. Kinnear Clark. With 36 plates and other illustrations. Imperial 8vo, cloth.......................................12 00

SLATER (J. W.). Sewage Treatment, Purification, and Utilization. A Practical Manual for the Use of Corporations, Local Boards, Medical Officers of Health, Inspectors of Nuisances, Chemists, Manufacturers, Riparian Owners, Engineers, and Ratepayers. 12mo, cloth................................ 2 25

SMITH (ISAAC W., C. E.). The Theory of Deflections and of Latitudes and Departures. With special applications to Curvilinear Surveys, for Alignments of Railway Tracks. Illustrated. 16mo, morocco, tucks.................................... 3 00

SNELL (ALBION T.). Electric Motive Power: The Transmission and Distribution of Electric Power by Continuous and Alternate Currents With a Section on the Applications of Electricity to Mining Work. Second edition. 8vo, cloth, illustrated.............. 4 00

SPEYERS (CLARENCE L.). Text-Book of Physical Chemistry. 8vo, cloth........................ 2 25

STAHL (A. W.), and A. T. WOODS. Elementary Mechanism. A Text-Book for Students of Mechanical Engineering. Fourth edition, enlarged. 12mo, cloth.. 2 00

STALEY (CADY), and PIERSON, GEO. S. The Separate System of Sewerage: its Theory and Construction. Third edition, revised. 8vo, cloth. With maps, plates and illustrations....................... 3 00

STEVENSON (DAVID, F.R.S.N.). The Principles and Practice of Canal and River Engineering. Revised by his sons David Alan Stevenson, B. Sc., F. R. S.E., and Charles Alexander Stevenson, B. Sc., F.R. S.E., Civil Engineer. Third edition, with 17 plates, 8vo, cloth.......................................10 00

—— The Design and Construction of Harbors, A Treatise on Maritime Engineering. Third edition with 24 plates, 8vo, cloth.............................. 9 00

STEWART (R. W.). A Text Book of Light, Adapted to the Requirements of the Intermediate Science and Preliminary Scientific Examinations of the University of London, and also for General Use, Numerous Diagrams and Examples. 12mo, cloth.. 1 00

STEWART (R. W.). A Text Book of Heat, Illustrated, 8vo, cloth.................................... 1 00

—— A Text Book of Magnetism and Electricity, 160 Illus. and Numerous Examples. 12mo, cloth....... 1 00

STILES (AMOS). Tables for Field Engineers. Designed for use in the field. Tables containing all the functions of a one degree curve, from which a corresponding one can be found for any required degree. Also, Tables of Natural Sines and Tangents. 12mo, morocco, tucks.................................. 2 00

STILLMAN (PAUL). Steam Engine Indicator and the Improved Manometer Steam and Vacuum Gauges; their Utility and Application. New edition. 12mo, flexible cloth........ .... 1 00

STONE (General ROY). New Roads and Road Laws in the United States. 200 pages, with numerous illustrations. 12mo, cloth.......................... 1 00

STUART (C. B., U. S. N.). Lives and Works of Civil and Military Engineers of America. With 10 steel-plate engravings. 8vo, cloth......... .... 5 00

—— The Naval Dry Docks of the United States. Illustrated with 24 fine Engravings on Steel. Fourth edition. 4to, cloth................................ 6 00

SWINTON (ALAN A. CAMPBELL). The Elementary Principle of Electric Lighting. Illustrated. 12mo, cloth 60

TEMPLETON (WM.). The Practical Mechanic's Work-shop Companion. Comprising a great variety of the most useful rules and formulæ in Mechanical Science, with numerous tables of practical data and calculated results facilitating mechanical operations. Revised and enlarged by W. S. Hutton. 12mo, morocco...................... .... 2 00

THOM (CHAS.), and WILLIS H. JONES. Telegraphic Connections: embracing Recent Methods in Quadruplex Telegraphy. Oblong, 8vo, cloth. 20 full page plates, some colored................. .... 1 50

THOMPSON (EDWARD P., M. E.). How to Make Inventions; or Inventing as a Science and an Art. A Practical Guide for Inventors. Second edition. 8vo, boards 1 00

—— Roentgen Rays and Phenomena of the Anode and Cathode. Principles, Applications and Theories. For Students, Teachers, Physicians, Photographers, Electricians and others. Assisted by Louis M. Pignolet, N. D. C. Hodges, and Ludwig Gutmann, E. E. With a Chapter on Generalizations, Arguments, Theories, Kindred Radiations and Phenomena. By Professor Wm. Anthony. 8vo, cloth. 50 Diagrams, 40 Half tones..... .... 1 50

TODD (JOHN), and W. B. WHALL. Practical Seamanship for Use in the Merchant Service: Including all ordinary subjects; also Steam Seamanship, Wreck Lifting, Avoiding Collision, Wire Splicing, Displacement, and everything necessary to be known by seamen of the present day. Second edition, with 247 illustrations and diagrams. 8vo, cloth.......... 8 40

TOOTHED GEARING. A Practical Hand-book for Offices and Workshops. By a Foreman Patternmaker. 184 Illustrations. 12mo, cloth.............. 2 25

TRATMAN (E. E. RUSSELL). Railway Track and Track Work. With over two hundred illustrations. 8vo, cloth 3 00

TREVERT (EDWARD). How to Build Dynamo-Electric Machinery, embracing Theory Designing and Construction of Dynamos and Motors. With appendices on Field Magnet and Armature Winding, Management of Dynamos and Motors, and Useful Tables of Wire Gauges. Illustrated. 8vo, cloth.... 2 50

—— Electricity and its Recent Applications. A Practical Treatise for Students and Amateurs, with an Illustrated Dictionary of Electrical Terms and Phrases. Illustrated. 12mo, cloth.................. 2 00

TUCKER (Dr. J. H.). A Manual of Sugar Analysis, including the Applications in General of Analytical Methods to the Sugar Industry. With an Introduction on the Chemistry of Cane Sugar. Dextrose, Levulose, and Milk Sugar. 8vo, cloth. Illustrated. 3 05

TUMLIRZ (Dr. O.). Potential and its Application to the Explanation of Electric Phenomena, Popularly Treated. Translated from the German by D. Robertson. Illustrated. 12mo, cloth............ .... 1 25

TUNNER (P. A.). Treatise on Roll-Turning for the Manufacture of Iron. Translated and adapted by John B. Pearse, of the Pennsylvania Steel Works, with numerous engravings, wood-cuts. 8vo, cloth, with folio atlas of plates...................... .10 00

URQUHART (J. W.). Electric Light Fitting. Embodying Practical Notes on Installation Management. A Hand-book for Working Electrical Engineers—with numerous illustrations. 12mo, cloth.. ..... . 2 00

—— Electro-Plating. A Practical Hand-book on the Deposition of Copper, Silver, Nickel, Gold, Brass, Aluminum, Platinum, etc. Fourth edition. 12mo.. 2 00

URQUHART, (J. W.). Dynamo Construction: a Practical Hand-book for the Use of Engineer Constructors and Electricians in Charge, embracing Frame Work Building, Field Magnet and Armature Winding and Grouping, Compounding, etc., with Examples of Leading English, American and Continental Dynamos and Motors, with numerous illustrations. 12mo, cloth 3 00

—— Electric Ship Lighting. A Hand-book on the Practical Fitting and Running of Ship's Electrical Plant. For the Use of Ship Owners and Builders, Marine Electricians and Sea Going Engineers-in-Charge. Numerous illustrations. 12mo, cloth 3 00

UNIVERSAL TELEGRAPH CIPHER CODE. Arranged for General Correspondence. 12mo, cloth. 1 00

VAN NOSTRAND'S ENGINEERING MAGAZINE. Complete sets, 1869 to 1886 inclusive.
Complete sets, 35 vols., in cloth 60 00
Complete sets, 35 vols., in half morocco 100 00

VAN WAGENEN (T. F.). Manual of Hydraulic Mining. For the Use of the Practical Miner. Revised and enlarged edition. 18mo, cloth......... 1 00

WALKER (SIDNEY F.). Electric Lighting for Marine Engineers, or How to Light a Ship by the Electric Light and How to Keep the Apparatus in Order. 103 illustrations. 8vo, cloth. Second edition. 2 00

WALLIS-TAYLER (A. J.). Modern Cycles. A Practical Hand-book on their Construction and Repair. With 300 illustrations. 8vo, cloth. 4 00

—— Motor Cars, or Power Carriages for Common Roads. 8vo, cloth, with numerous illustrations..... 1 80

—— Bearings and Lubrication. A Hand-book for every user of Machinery. 8vo, cloth, fully illustrated 1 50

—— Refrigerating and Ice-Making Machinery. A Descriptive Treatise for the use of persons employing refrigerating and ice-making installations and others. 8vo, cloth. Illustrated 3 00

—— Sugar Machinery. A Descriptive Treatise. Devoted to the Machinery and Apparatus used in the Manufacture of Cane and Beet Sugars. 12mo, cloth. Illustrated 2 00

WANKLYN (J. A.). A Practical Treatise on the Examination of Milk and its Derivatives, Cream, Butter, and Cheese. 12mo, cloth.......... .. 1 00

—— Water Analysis. A Practical Treatise on the Examination of Potable Water. Tenth Edition. 12mo, cloth................ .... 2 00

WANSBROUGH (WM. D.). The A. B. C. of the Differential Calculus. 12mo, cloth.... .... 1 50

WARD (J. H.). Steam for the Million. A Popular Treatise on Steam, and its application to the Useful Arts, especially to Navigation. 8vo, cloth 1 00

WARING (GEO. E., Jr.). Sewerage and Land Drainage. Illustrated with wood-cuts in the text, and full-page and folding plates. Quarto. Cloth. Third edition...... .... 6 00

—— Modern Methods of Sewage Disposal for Towns, Public Institutions and Isolated Houses. Second edition, revised and enlarged. 260 pages. Illustrated. Cloth........... .... 2 00

—— How to Drain a House. Practical Information for Householders. New and enlarged edition. 12mo, cloth 1 25

WATSON (E. P.). Small Engines and Boilers. A Manual of Concise and Specific Directions for the Construction of Small Steam Engines and Boilers of Modern Types from five Horse-power down to model sizes. 12mo, cloth. Illustrated with Numerous Diagrams and Half Tone Cuts. New York, 1899...... 1 25

WATT (ALEXANDER). Electro-Deposition. A Practical Treatise on the Electrolysis of Gold, Silver, Copper, Nickel, and other Metals, with Descriptions of Voltaic Batteries, Magneto and Dynamo-Electric Machines, Thermopiles, and of the Materials and Processes used in every Department of the Art, and several chapters on Electro-Metallurgy. With numerous illustrations. Third edition, revised and corrected. Crown, 8vo, 568 pages 3 50

—— Electro-Metallurgy Practically Treated. Tenth edition, considerably enlarged. 12mo, cloth. 1 00

—— The Art of Soap-Making. A Practical Hand-book of the Manufacture of Hard and Soft Soaps, Toilet Soaps, &c. Including many New Processes, and a Chapter on the Recovery of Glycerine from Waste Leys. With illustrations. Fourth edition, revised and enlarged. 8vo.. 3 00

WATT (ALEXANDER). The Art of Leather Manufacture. Being a Practical Hand-book, in which the Operations of Tanning, Currying, and Leather Dressing are Fully Described, and the Principles of Tanning Explained, and many Recent Processes Introduced. With numerous illustrations. Second edition. 8vo, cloth 4 00

WEALE (JOHN). A Dictionary of Terms Used in Architecture, Building, Engineering, Mining, Metallurgy. Archaeology, the Fine Arts etc., with explanatory observations connected with applied Science and Art. Fifth edition, revised and corrected. 12mo, cloth 2 50

—— Weale's Rudimentary Scientific Series (Catalogue sent on application).

WEBB (HERBERT LAWS). A Practical Guide to the Testing of Insulated Wires and Cables. Illustrated. 12mo, cloth 1 00

—— The Telephone Hand-book. 128 illustrations. 146 pages. 16mo, cloth 1 00

WEEKES (R. W.). The Design of Alternate Current Transformers. Illustrated. 12mo, cloth 1 00

WEISBACH (JULIUS). A Manual of Theoretical Mechanics. Ninth American edition. Translated from the fourth augmented and improved German edition, with an Introduction to the Calculus by Eckley B. Coxe, A. M., Mining Engineer. 1,100 pages, and 902 wood-cut illustrations. 8vo, cloth 6 00
Sheep 7 50

WESTON (EDMUND B.). Tables Showing Loss of Head Due to Friction of Water in Pipes. Second edition. 12mo, cloth 1 50

WEYMOUTH (F. MARTEN). Drum Armatures and Commutators. (Theory and Practice.) A complete Treatise on the Theory and Construction of Drum Winding, and of commutators for closed-coil armatures, together with a full resume of some of the principal points involved in their design, and an exposition of armature re-actions and sparking. 8vo, cloth 3 00

WEYRAUCH (J. J.). Strength and calculations of Dimensions of Iron and Steel Construction, with reference to the Latest Experiments. 12mo, cloth, plates 1 00

WHEELER (Prof. J. B.). Art of War. A Course of Instruction in the Elements of the Art and Science of War, for the Use of the Cadets of the United States Military Academy, West Point, N. Y. 12mo, cloth	1 75
—— Field Fortifications. The Elements of Field Fortifications, for the Use of the Cadets of the United States Military Academy, West Point, N. Y. 12mo.	1 75
WHIPPLE (S., C. E.). An Elementary and Practical Treatise on Bridge Building. 8vo, cloth	3 00
WILKINSON (H. D.). Submarine Cable-Laying, Repairing and Testing. 8vo, cloth	4 00
WILLIAMSON (R. S.). On the Use of the Barometer on Surveys and Reconnoissances. Part I. Meteorology in its Connection with Hypsometry. Part II. Barometric Hypsometry. With illustrative tables and engravings. 4to, cloth	15 00
WILLIAMSON (E. S.). Practical Tables in Meteorology and Hpsometry, in connection with the use of the Barometer. 4to, cloth	2 50
WILSON (GEO.). Inorganic Chemistry, with New Notation. Revised and enlarged by H. G. Madan. New edition. 12mo, cloth	2 00
WOODBURY (D. V.). Treatise on the Various Elements of Stability in the Well-Proportioned Arch. 8vo, half morocco	4 00
WRIGHT (T. W.). A Treatise on the Adjustment of Observations. With applications to Geodetic Work, and other Measures of Precision. 8vo, cloth	4 00
—— Elements of Mechanics; including Kinematics, Kinetics and Statics. With application. 8vo, cloth	2 50
WYLIE (CLAUDE). Iron and Steel Founding. Illustrated with 39 diagrams. Second edition, revised and enlarged. 8vo, cloth	2 00
WYNKOOP (RICHARD). Vessels and Voyages, as Regulated by Federal Statutes and Treasury Instructions and Decisions. 8vo, cloth	2 00
YOUNG (J. ELTON). Electrical Testing for Telegraph Engineers, with Appendices consisting of Tables. 8vo, cloth. Illustrated	4 00
YOUNG SEAMAN'S MANUAL. Compiled from Various Authorities, and Illustrated with Numerous Original and Select Designs, for the Use of the United States Training Ships and the Marine Schools. 8vo, half roan	3 00

..THE..

VAN NOSTRAND SCIENCE SERIES

16mo. Boards. Price 50 Cents Each.

mply Illustrated when the Subject Demands.

1.—**CHIMNEYS FOR FURNACES AND STEAM BOILERS.** By R. Armstrong, C. E. Third American edition. Revised and partly rewritten, with an Appendix on Theory of Chimney Draught, by F. E. Idell, M. E.

2.—**STEAM BOILER EXPLOSIONS.** By Zerah Colburn. New edition, revised by Prof. R. H. Thurston.

3.—**PRACTICAL DESIGNING OF RETAINING-WALLS.** By Arthur Jacob, A. B. Second edition, revised, with additions by Prof. W. Cain.

4.—**PROPORTIONS OF PINS USED IN BRIDGES.** By Chas. E. Bender, C. E. Second edition, with appendix.

5.—**VENTILATION OF BUILDINGS.** By W. F. Butler. Second edition, re-edited and enlarged by James L. Greenleaf, C. E.

6.—**ON THE DESIGNING AND CONSTRUCTION OF STORAGE RESERVOIRS.** By Arthur Jacob, A. B. Second edition, revised, with additions by E. Sherman Gould.

7.—**SURCHARGED AND DIFFERENT FORMS OF RETAINING-WALLS.** By James S. Tate, C. E.

8.—**A TREATISE ON THE COMPOUND ENGINE.** By John Turnbull, Jun. Second edition, revised by Prof. S. W. Robinson.

9—**A TREATISE ON FUEL.** By Arthur V. Abbott, C. E. Founded on the original treatise of C. William Siemens, D. C. L.

10.—**COMPOUND ENGINES.** Translated from the French of A. Mallet. Second edition, revised with results of American Practice, by Richard H. Buel, C. E.

No. 11.—**THEORY OF ARCHES.** By Prof. W. Allan.

No. 12.—**THEORY OF VOUSSOIR ARCHES.** By Prof. W. G. Cain. Second edition, revised and enlarged.

No. 13.—**GASES MET WITH IN COAL MINES.** By J. J. Atkinson. Third edition, revised and enlarged by Edward H. Williams, Jun.

No. 14.—**FRICTION OF AIR IN MINES.** By J. J. Atkinson. Second American edition.

No. 15.—**SKEW ARCHES.** By Prof. E. W. Hyde, C. E. Illustrated. Second edition.

No. 16.—**A GRAPHIC METHOD FOR SOLVING CERTAIN ALGEBRAIC EQUATIONS.** By Prof. G. L. Vose.

No. 17.—**WATER AND WATER-SUPPLY.** By Prof. W. H. Corfield, of the University College, London. Second American edition.

No. 18.—**SEWERAGE AND SEWAGE PURIFICATION.** By M. N. Baker, Associate Editor "Engineering News."

No. 19.—**STRENGTH OF BEAMS UNDER TRANSVERSE LOADS.** By Prof. W. Allan, author of "Theory of Arches." Second edition, revised.

No. 20.—**BRIDGE AND TUNNEL CENTRES.** By John B. McMaster, C. E. Second edition.

No. 21.—**SAFETY VALVES.** Third edition. By Richard H. Buel, C. E.

No. 22.—**HIGH MASONRY DAMS.** By E. Sherman Gould, M. Am. Soc. C. E.

No. 23.—**THE FATIGUE OF METALS UNDER REPEATED STRAINS.** With various Tables of Results and Experiments. From the German of Prof. Ludwig Spangenburgh, with a Preface by S. H. Shreve, A. M.

No. 24.—**A PRACTICAL TREATISE ON THE TEETH OF WHEELS.** By Prof. S. W. Robinson. Second edition, revised.

No. 25.—**ON THE THEORY AND CALCULATION OF CONTINUOUS BRIDGES.** By Mansfield Merriman, Ph. D.

No. 26.—**PRACTICAL TREATISE ON THE PROPERTIES OF CONTINUOUS BRIDGES.** By Charles Bender, C. E.

No. 27.—**ON BOILER INCRUSTATION AND CORROSION.** By F. J. Rowan. New edition. Revised by F. E. Idell.

No. 28.—**TRANSMISSION OF POWER BY WIRE ROPES.** Second edition. By Albert W. Stahl, U. S. N.

No. 29.—**STEAM INJECTORS.** Translated from the French of M. Leon Pochet.

No. 30.—**TERRESTRIAL MAGNETISM AND THE MAGNETISM OF IRON VESSELS.** By Prof. Fairman Rogers.

No. 31.—**THE SANITARY CONDITION OF DWELLING-HOUSES IN TOWN AND COUNTRY.** Second edition, revised. By George E. Waring, Jun.

No. 32.—**CABLE-MAKING FOR SUSPENSION BRIDGES.** By W. Hildebrand, C. E.

No. 33.—**MECHANICS OF VENTILATION.** By George W. Rafter, C. E. New and Revised Edition.

No. 34.—**FOUNDATIONS.** By Prof. Jules Gaudard, C. E. Second edition. Translated from the French.

No. 35.—**THE ANEROID BAROMETER: ITS CONSTRUCTION AND USE.** Compiled by George W. Plympton. Seventh edition, revised and enlarged.

No. 36.—**MATTER AND MOTION.** By J. Clerk Maxwell, M. A. Second American edition.

No. 37.—**GEOGRAPHICAL SURVEYING; ITS USES, METHODS AND RESULTS.** By Frank De Yeaux Carpenter, C. E.

No. 38.—**MAXIMUM STRESSES IN FRAMED BRIDGES** By Prof. William Cain, A. M., C. E. New and revised edition.

No. 39.—**A HAND-BOOK OF THE ELECTRO-MAGNETIC TELEGRAPH.** By A. E. Loring.

No. 40.—**TRANSMISSION OF POWER BY COMPRESSED AIR.** By Robert Zahner, M. E. Second edition.

No. 41.—**STRENGTH OF MATERIALS.** By William Kent, C. E., Assoc. Editor, "Engineering News." Second edition.

No. 76.—**MODERN REPRODUCTIVE GRAPHIC PROCESSES.** By Lieut. James S. Pettit, U.S.A.

No. 77.—**STADIA SURVEYING.** The Theory of Stadia Measurements. By Arthur Winslow.

No. 78.—**THE STEAM-ENGINE INDICATOR, AND ITS USE.** By W. B. LeVan.

No. 79.—**THE FIGURE OF THE EARTH.** By Frank C. Roberts, C. E.

No. 80.—**HEALTHY FOUNDATIONS FOR HOUSES.** By Glenn Brown.

No. 81.—**WATER METERS: COMPARATIVE TESTS OF ACCURACY, DELIVERY, Etc.,** Distinctive features of the Worthington, Kennedy, Siemens, and Hesse meters. By Ross E. Browne.

No. 82.—**THE PRESERVATION OF TIMBER BY THE USE OF ANTISEPTICS.** By Samuel Bagster Boulton, C. E.

No. 83.—**MECHANICAL INTEGRATORS.** By Prof. Henry S. H. Shaw, C. E.

No. 84.—**FLOW OF WATER IN OPEN CHANNELS, PIPES, CONDUITS, SEWERS, Etc.** With Tables. By P. J. Flynn, C. E.

No. 85.—**THE LUMINIFEROUS ÆTHER.** By Prof. de Volson Wood.

No. 86.—**HAND-BOOK OF MINERALOGY; DETERMINATION AND DESCRIPTION OF MINERALS FOUND IN THE UNITED STATES.** By Prof. J. C. Foye, Sixth edition, revised.

No. 87.—**TREATISE ON THE THEORY OF THE CONSTRUCTION OF HELICOIDAL OBLIQUE ARCHES.** By John L. Culley, C. E.

No. 88.—**BEAMS AND GIRDERS.** Practical Formulas for their Resistance. By P. H. Philbrick.

No. 89.—**MODERN GUN COTTON: ITS MANUFACTURE, PROPERTIES, AND ANALYSIS.** By Lieut. John P. Wisser, U.S.A.

No. 90.—**ROTARY MOTION AS APPLIED TO THE GYROSCOPE.** By Gen. J. G. Barnard.

No. 91.—**LEVELING: BAROMETRIC TRIGONOMETRIC, AND SPIRIT.** By Prof. I. O. Baker.

No. 92.—**PETROLEUM: ITS PRODUCTION AND USE.** By Boverton Redwood, F. I. C., F. C. S.

No. 93.—**RECENT PRACTICE IN THE SANITARY DRAINAGE OF BUILDINGS.** With Memoranda on the Cost of Plumbing Work. Second edition, revised. By William Paul Gerhard, C. E.

No. 94.—**THE TREATMENT OF SEWAGE.** By Dr. C. Meymott Tidy.

No. 95.—**PLATE GIRDER CONSTRUCTION.** By Isami Hiroi, C. E. 2d edition, revised and enlarged.

No. 96.—**ALTERNATE CURRENT MACHINERY.** By Gisbert Kapp, Assoc. M. Inst., C. E.

No. 97.—**THE DISPOSAL OF HOUSEHOLD WASTES.** By W. Paul Gerhard, Sanitary Engineer.

No. 98.—**PRACTICAL DYNAMO BUILDING FOR AMATEURS. HOW TO WIND FOR ANY OUTPUT.** By Frederick Walker. Fully illustrated.

No. 99.—**TRIPLE-EXPANSION ENGINES AND ENGINE TRIALS.** By Prof. Osborne Reynolds. Edited with notes, etc., by F. E. Idell, M. E.

No. 100.—**HOW TO BECOME AN ENGINEER,** or the Theoretical and Practical Training necessary in fitting for the duties of the Civil Engineer. By Prof. Geo. W. Plympton.

No. 101.—**THE SEXTANT,** and other Reflecting Mathematical Instruments. With Practical Hints for their adjustment and use. By F. R. Brainard, U. S. Navy.

No. 102.—**THE GALVANIC CIRCUIT INVESTIGATED MATHEMATICALLY.** By Dr. G. S. Ohm, Berlin, 1827. Translated by William Francis. With Preface and Notes by the Editor, Thomas D. Lockwood, M. I. E. E.

No. 103.—**THE MICROSCOPICAL EXAMINATION OF POTABLE WATER.** With Diagrams. By Geo. W. Rafter.

No. 104.—**VAN NOSTRAND'S TABLE BOOK FOR CIVIL AND MECHANICAL ENGINEERS.** Compiled by Prof. Geo. W. Plympton.

No. 105.—**DETERMINANTS.** An Introduction to the Study of, with Examples and Applications. By Prof. G. A. Miller.

No. 106.—**COMPRESSED AIR.** Experiments upon the Transmission of Power by Compressed Air in Paris. (Popp's System.) By Prof A. B. W. Kennedy. The Transmission and Distribution of Power from Central Stations by Compressed Air. By Prof. W. C. Unwin.

No. 107.—**A GRAPHICAL METHOD FOR SWING BRIDGES.** A Rational and Easy Graphical Analysis of the Stresses in Ordinary Swing Bridges. With an Introduction on the General Theory of Graphical Statics. By Benjamin F. La Rue. 4 Plates.

No. 108.—**SLIDE VALVE DIAGRAMS.** A French Method for Constructing Slide Valve Diagrams. By Lloyd Bankson, B. S., Assistant Naval Constructor, U. S. Navy. 8 Folding Plates.

No. 109.—**THE MEASUREMENT OF ELECTRIC CURRENTS.** Electrical Measuring Instruments. By James Swinburne. Meters for Electrical Energy. By C. H. Wordingham. Edited, with Preface, by T. Commerford Martin. Folding Plate and numerous illustrations.

No. 110.—**TRANSITION CURVES.** A Field-Book for Engineers, containing Rules and Tables for Laying out Transition Curves. By Walter G. Fox, C. E.

No. 111.—**GAS-LIGHTING AND GAS-FITTING.** Specifications and Rules for Gas-Piping. Notes on the advantages of Gas for Cooking and Heating, and Useful Hints to Gas Consumers. Second edition, rewritten and enlarged. By Wm. Paul Gerhard, C. E.

No. 112.—**A PRIMER ON THE CALCULUS.** By E. Sherman Gould, M. Am. Soc. C. E. Second edition, revised and enlarged.

No. 113.—**PHYSICAL PROBLEMS** and their Solution. By A. Fourgougnon, Formerly Assistant at Bellevue Hospital.

No. 114.—**MANUAL OF THE SLIDE RULE.** By F. A. Halsey, of the *American Machinist*.

No. 115.—**TRAVERSE TABLE** showing the difference of Latitude and Departure for distances between 1 and 100 and for Angles to Quarter Degrees between 1 degree and 90 degrees. (Reprinted from Scribner's Pocket Table Book.)

[illegible]